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Department of Energy Funding Priorities:
AN EXPERT DISCUSSION

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Introduction and Executive Summary

Near Zero organized a discussion of energy experts on the factors that should be considered by Department of Energy when allocating its resources among programs.

On March 22, 2011, Near Zero invited 64 experts from industry, academia, government and non-governmental organizations to participate in an email discussion of DOE funding priorities, with reference to the Department of Energy (DOE) Quadrennial Technology Review (QTR) Framing Document.[1] As we explained to the expert invitees, "Our goal [was] to provide an efficient and fun way for you to leverage your expertise to advance decision makers' understanding of important energy issues."

We first asked for answers to the following question: "What are the factors that DOE should consider in allocating RD&D resources among technologies of disparate maturity and potential time to impact?" Our instructions continued, "At this point we are simply asking for factors that should be considered, such as 'today's cost per unit output', or 'achieved thermodynamic efficiency relative to maximum theoretical thermodynamic efficiency', 'social acceptability', etc."

1 Available online at: http://www.energy.gov/qtr/documents/DOE-QTR_Framing.pdf

Over the course of 24 days, we received more than 30 responses from 15 energy experts. Here, we organize and summarize the responses. A complete transcript of the emails we received is included as Appendix I.

The experts discussed factors of materiality, cost-effectiveness, and maturity, as well as the necessity of DOE support, potential to reduce energy demand, the effect on U.S. competitiveness and energy security, and technology lock-in. In addition to investment criteria, experts offered general recommendations for improving the informational basis for decisions, the importance of stable and increased funding, and the need to invest in diffusion of what is already known.

Each expert was also invited to address the merits of specific technologies in the context of different factors. Several emphasized the need to reduce demand through efficiency gains at both the device and system levels. In considering the major categories of clean electricity, materiality, maturity and the necessity of DOE funding were common considerations. Cost-effectiveness was also raised several times.

Frameworks, Goals and Strategies

Although the immediate question was one of "factors that DOE should consider in allocating RD&D resources," several experts also discussed overarching goals and high-level frameworks for the more specific factors.

For instance, Hal Harvey of ClimateWorks described three policy approaches: "a) performance standards; b) economic signals; and c) R&D," and emphasized that these approaches, "…are highly complementary, and none can do the job alone."

Similarly, Jay Apt of Carnegie Mellon University cited a National Research Council (NRC) study[2] which delineated three primary effects of DOE programs: "(1) reduction of technical risk, (2) reduction of market risk, and (3) acceleration of technology to market." Specific programs were then evaluated "…on the basis of completion costs, economic benefits (cumulative net savings), environmental benefits (cumulative reduction in emissions), and security benefits (cumulative reduction in resource consumption)."

Arnulf Grubler of the International Institute for Applied Systems Analysis called out a range of objectives similar to those in the study cited by Professor Apt: "energy security, climate change mitigation, reduction of energy poverty and providing adequate energy services for economic development."

GianCarlo Tosato of the International Energy Agency's Energy Technology Systems Analysis Program also enumerated a similar set of four "quantitative dimensions of the energy technologies system and its future behavior…energy (including security), engineering (including learning), environment (including climate changes), and economy (including sustainability)." He also mentioned "qualitative dimensions" such as "social, political, administrative, safety, etc."

Others, such as Jane Long of Lawrence Livermore National Laboratory, primarily addressed the goal of reducing carbon emissions: "[T]here are 4 key strategies in reducing carbon from the energy system and these strategies should inform research priorities:1) Increase efficiency in buildings, industry and transportation, 2) Electrify transportation and heat, 3) De-carbonize electricity, [and] 4) De-carbonize the fuel supply."

In contrast, Lee Lane of the Hudson Institute stated, "The prospects for global decarbonization are so distant that it may be useful to set priorities with more diverse public goals in mind. … DOE's focal point should be to enhance the scientific knowledge, tools, and techniques employed by others in the pursuit of more fuel and food." A different view—but one conscious of political feasibility—was expressed by Christopher Green of McGill University, who wrote, "[G]etting bi-partisan support for fully funded expenditures on something every one benefits from (the energy system), might be possible as Congress begins to look at entitlement, other expenditure, and tax reform as it takes up the deficit-debt problem."

As a general strategy, Nate Lewis of the California Institute of Technology advised, "DOE needs a portfolio of time horizons and risk profiles in order to maximize its chances of success."

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2 Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two), Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs (Phase Two), National Research Council, ISBN: 0-309-66840-9, 234 pages, (2007), http://www.nap.edu/catalog/11806.html

Factors for Consideration

Experts suggested a number of factors that the DOE should consider in allocating its resources. The following summary is organized by those factors.

Materiality

Several experts were primarily concerned with whether a technology would ever contribute materially to meeting global energy demand and/or reducing global carbon emissions. For example, Christopher Green made a case that "the main concern is with priorities for low carbon technologies that could be made sufficiently scalable that they can make an important contribution to stabilizing atmospheric carbon concentration at an acceptable level." Likewise, Martin Hoffert of New York University stressed the need to "…assess the potential of these technologies to generate the 10-30 terawatts of carbon-neutral sustainable power to achieve the President's goal of 80% reductions in carbon emissions by mid-century." Max Henrion of Lumina Decision Systems, Inc. emphasized scalability, as well, but added a focus on high risk technologies: "We need to be looking for…technologies that may have only a small probability of technical success, but with a potential huge impact." Relatedly, Hal Harvey advised that the DOE "pay attention to raw materials constraints," which could limit scalability. But Jay Apt put it the most plainly: "Is the technology ever going to be important?"

Cost-effectiveness

Lee Schipper of Stanford University took the position that, "Only an economic framework allows us to get close to comparing apples with apples." Jay Apt again summarized the factor of cost-effectiveness nicely: "Is the investment likely to bring costs to the range of other low-carbon power costs?"

In the context of evaluating costs, several experts noted the importance of internalizing externalities. "[A]s long as we hide the cost of new energy sources or energy-using systems with 'incentives' we never try to fit our demand to the costs of getting energy from those systems," noted Lee Schipper. GianCarlo Tosato, "assum[ed] that long term consideration[s] prevail over short term ones, and the value of public goods which do not have a market price [are] included in the picture." William Moomaw stated, "measuring economic damage costs is one good way to compare these otherwise incomparable aspects along with the direct economic costs of using a particular source and comparing it to other options."

More than one expert also pointed out deficiencies of forecasting returns on investments in energy technologies. For instance, Martin Hoffert commented, "[E]conomists don't have a great track record forecasting which technologies will break through costwise and which will hit unanticipated show-stoppers, or show-delayers, like Spiderman accidents on Broadway and Fukashima light water reactor accidents in Japan." Ken Caldeira noted, "[W]e are making decisions under uncertainty and we do not know in advance those curves that would show us expected change in performance as a function of investment."

Max Henrion had a somewhat different take: "Some have argued that the degree of uncertainty about outcomes of R&D makes it impractical to do quantitative comparisons among technology. On the contrary, the uncertainty makes it even more important to do so, and to be explicit about the uncertainties. Explicit risk analysis is critical if you are to appropriately evaluate and compare competing high-risk projects. A useful approach (suggested by the [NRC] study cited by Jay Apt [supra note 1]) is to use expert elicitation to estimate the uncertainty about future cost-performance of each technology expressed as probability distributions over key metrics (such as $/KW or $/Kwh) conditional on levels of R&D funding." Dr. Henrion acknowledged that this approach is "challenging to do well," but pointed out that he has assisted the DOE's Office of Energy Efficiency and Renewable Energy to develop such a protocol, as well as the National Renewable Energy Lab to develop "[a] dynamic stochastic computer model [that] can help us explore and understand…complex [economic and policy] interactions, identify a variety of plausible scenarios, and prevent us fixating on a single 'expected' future."

Considering the specific externality of carbon emissions and the need for investments in immature technologies with uncertain returns, Christopher Green argued, "[W]e need to put to rest the idea that levying a carbon price (tax) will induce into existence the needed technologies [to reduce emissions substantially]. Much of what is needed is science-driven basic research and development, followed by testing and demonstration of technologies that are (i) uncertain of success, (ii) if successful, are likely to provide payoff that begin only decades rather than years in the future, and (iii) have benefits that for the most part are not privately appropriable." Nonetheless, Lee Schipper asserted, "Without any carbon price at all we are up to the whims of a much higher growth rate in demand. … PV and many other potential energy resources, as well as nuclear (if that is still a resource) still are too expensive to compete with oil and gas and most of all coal. And if we cannot raise the price of energy before it ultimately raises itself, we cannot pay for the new sources. I do not believe R&D alone can make them 'cheap' and I do not believe they need to be 'cheap'." Yet Dr. Green concluded, "[B]reakthroughs will be needed to assure at least a modicum of cost competitiveness."

Maturity

Lee Lane articulated what seems to be a common view among the experts who participated in our discussion that "the question of what stage of the R&D process at which public funding should cease is at least as important as the selection of specific technologies." In Mr. Lane's view, "… technologies that have, or that purport to have, commercial value, government spending needs to stay well upstream of commercialization." Max Henrion echoed this, arguing that, "For technologies with moderate risks and potential returns in the not-too-distant future, the private sector should already be making appropriate investments, and usually is. There seems little reason for DOE to be funding RD&D in relatively mature technologies already widely commercialized (such as wind turbines)." Dale Simbeck made a related argument that, "The best Gov. funded R&D ideas end up with researchers that leave the safety of 'white collar welfare' (simply telling the funder whatever they want to hear) to start their own high-risk energy or environmental technology start-up company."

Instead, as signaled by the comments above regarding the necessity of investments in fundamental research and early stage R&D despite uncertain returns, Dr. Henrion stated, "DOE should support high-risk early-stage projects, as ARPA-E is already doing, but with expanded funding." Put differently, Hal Harvey recommended that the DOE "…[f]ocus special attention on promising technologies where there is no obvious market maker."

Also with respect to maturity of technologies, Jay Apt cited and described a comprehensive strategy:[3]

> [I]n 1st gen R&D, the insights and experience of tech managers determine investment, with no particular link to the organization's strategy. 2nd gen R&D measures project progress with respect to a set of goals and the project costs are compared to possible benefits to the organization. In 3rd gen, tech managers and the organization's top folks form a partnership to select projects aligned with the organization's goals and evaluate them, using a portfolio approach to deal with risk. The portfolio recognizes the differences among incremental (defends and expands current business), radical (drives new business), and fundamental (makes the organization technically competent as a leader) research.

Perhaps underscoring a need for radical approaches, Dr. Apt also suggested the DOE ask, "Can the investment lead to increased innovation in the energy sector?"

Necessity of DOE Support

Moving beyond the "three M's" of materiality, money and maturity, our discussion raised a number of other possible criteria. Among the other possibilities, several experts recommended the DOE focus on R&D that would not be pursued without DOE funding. For example, Max Henrion urged the DOE to "…support projects with high initial costs and payback periods too long for commercial investors—such as, CCS, nuclear, and enhanced geothermal." Similarly, Hal Harvey's recommendation was to "…[f]ocus special attention on technologies with billion dollar stair-steps in their learning curves." Jane Long of Lawrence Livermore National Lab stated, "The Office of Science at DOE should be in the business of developing options and should do those things that venture money will not do. For example,

3 Roussel, P. A., Saad, K. N., and Erickson, T. J., 1991, Third Generation R & D: Managing the Link to Corporate Strategy: Boston, MA, Harvard Business Press, p. 192

there is a lot of venture money in biofuels and solar energy with perhaps some exceptions for basic science to underlie these technologies." Distilled to a question, Jay Apt asked simply, "Does DOE's investment have the prospect for solving a serious industry problem that is unlikely to be solved without DOE investment?"

Supply and Demand

Quite a lot of discussion centered on the importance of programs to decrease energy demand. Many of the comments above regarding externalities and cost-effectiveness were offered in this context. For example, Lee Schipper asserted, "If Americans really had to pay for energy, we'd learn to use it much more efficiently than with the improvements of the past 30 years. … What DOE research seems to lack is a [view] of how people will use technologies, and how the costs of those technologies might shape demand differently than we see it today." Relating back to the necessity of DOE involvement, Dr. Schipper stated, "No home builder, real estate speculator, or other actor has any incentive to [improve the systematic efficiency of buildings, so we should] try to get the most overall welfare (not just knowledge) from public investments in R&D where there is no private incentive, particularly if the results cannot be 'owned'." Hal Harvey echoed this, saying, "NO ONE in charge of system optimization." Arnulf Grubler of the International Institute of Applied Systems Analysis noted, "[E]nergy efficiency is significantly underrepresented in both public and private energy R&D portfolios worldwide."

However, Christopher Green warned that "[A]s long as we think that the main answer to the climate problem is to raise the price of energy and focus on energy efficiency we will fail to face the energy technology challenge posed by any effective attempt to stabilize climate." Lee Schipper replied, "I agree [with Dr. Green] that efficiency alone will not stabilize the climate. It just makes that feat much easier to accomplish, particularly on a global scale." Hal Harvey also agreed that, "Our remaining carbon budget does not allow us the luxury of choosing between efficiency and low-carbon supply technologies—so that debate is beside the point."

Several experts noted that efficiency gains reinforce the efficacy of new energy supply. William Moomaw pointed out that, "[t]he scope of renewable contributions is greatly enhanced by requiring lower end use energy requirements due to the smaller power densities of some renewables." Steven Hamburg of the Environmental Defense Fund stated, "[I]nefficient energy use provides the largest potential to reduce fossil fuel demand and ghg emissions." Likewise, Arnulf Grubler described multiple benefits: "Lower demand (growth) improves not only the leverage effect of low- and zero-carbon supply options, and thus a double dividend for GHG emission reductions, but also has direct benefits for traditional air pollutants (human health), and energy security (lessened import needs and greater leverage effect of domestic energy production)." Considering cost-effectiveness of emissions reductions, Dale Simbeck of SFA Pacific, Inc. argued, "The only carbon and CO_2 mitigation options that do not hurt our economy and reduce our economic competitiveness are conservation and efficiency, [but these are] marginalized to simple options (like florescent light bulbs) to avoid disruptive changes in big established industries." Vaclav Smil of the University of Manitoba emphasized the longevity of buildings, recommending "…we enact necessary building codes…to build ONLY new energy-efficient structures (they stay for decades)."

Arnulf Grubler made an additional point that, "[E]nergy efficiency R&D projects also tend to be 'granular' (smaller project scale in terms of $ needed) and thus offer significantly lower innovation risks." Furthermore, citing Robert Fri's review of the NRC 2001 study,[4] "energy efficiency R&D projects have been the most successful in past DOE R&D projects, both in terms of success as well as social rates of return."

Global Scope

A number of experts made comments relevant to the DOE's interest in balancing international competitiveness and cooperation while pursuing domestic objectives of energy security, economic competitiveness, and reduced environmental impacts.[5]

4 Fri, R.W., 2003, The Role of Knowledge: Technological Innovation in the Energy System: Energy Journal, v. 24, no. 4, p. 51-74.

5 See, e.g., section 5.2.1 of the DOE QTR Framing Document, as well as videotaped comments by Under Secretary for Science Steven Koonin: http://www.youtube.com/watch?v=W0JtMBMc9f0&feature=player_embedded

Jay Apt noted, “We sell wet flue gas desulfurization units worldwide in large part because our regulatory environment got there before the rest of the world’s did. On the other hand, we are quite likely to be importing CCS technology, and probably Gen 4 nuclear technology.” Dr. Apt suggested that, when allocating resources, the DOE should consider the question, “Will the investment increase American industry’s global competitiveness?”

Max Henrion elaborated on Dr. Apt’s suggestion, recommending that the DOE “emphasize a fourth metric [beyond levelized cost of energy, GHG emissions, and energy security] for evaluating its RD&D spending: The potential of the technical success of each R&D program to build a successful domestic industry and green jobs. While this objective is even harder to estimate than the first three metrics, it may get inadequate attention if it is not included explicitly along with the other three metrics. Given the very modest RD&D funds available to DOE ($4.3 billion, only 2% of the over $200 billion world clean-tech expenditures in 2010, according to the recent [Pew Charitable Trusts] report[6]), it would be wise to set a careful strategic focus on those technologies most likely to result in a domestic industry, and perhaps cede some technologies and markets if the USA is not willing to invest enough to cover the full range.” Also related to competitiveness, Dale Simbeck pointed out that “High U.S. carbon (or CO_2) taxes simply trash our economy unless we place the equivalent tax on carbon produce in production and shipping of imports [cites Davis and Caldeira, 2010].”[7]

On the side of collaboration, Christopher Green suggested that “individual national priorities might be based to some extent on national ‘comparative advantages’ (e g., Canada, China and U.S. re CCS) and to some extent on the efforts of competing international consortia that pick technologies where they have an abundance of the needed scientific and engineering expertise.” Dr. Green concluded, “[W]e need breakthroughs on many fronts and prioritizing should be done with an eye to what others are doing and what countries can usefully do collectively.”

Thermodynamics

Hal Harvey recommended that DOE “[p]ursue technologies that are not near their thermodynamic asymptote.” Nate Lewis noted, “Thermodynamic potential does not necessarily translate into economic potential because entropy plays a huge role as well as the first law of thermodynamics.”

Energy Security

To the extent energy security is an explicit goal of DOE programs, the NRC report cited by Jay Apt (supra note 1) suggested that economic valuation of energy security is not possible, and that evaluations should instead be based on physical quantities of fossil fuel consumption that could be avoided over time and the likely state of global markets in those fuels in the future.

Path Dependence

In addition to comments on maturity and uncertain returns, Martin Hoffert and William Moomaw were concerned with the path dependence of DOE investments. Dr. Moomaw explained, “There is a process to innovation and industrialization, and we cannot hang on to what we had when its time has passed. That said, we can find ways to smooth the transition for those who are inevitably displaced by innovation.” Dr. Hoffert offered some context: “[T]echnologies adopted for irrational reason often become locked in and very hard to dislodge politically, like Hyman Rickover’s [light water reactor] design for the first nuclear submarine paid for by the U.S. navy becoming the prototype for 85% of the world’s reactors (Chernobyl was copied from an even more primitive graphite ‘atomic pile’ Enrico Fermi’s team built under the U of Chicago squash courts in 1942).”

6 The Pew Charitable Trusts, “Who’s Winning the Clean Energy Race? Growth, Competition and Opportunity in the World’s Largest Economies,” 2010: http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Global_warming/G-20%20Report.pdf?n=5939

7 Davis, S. J., and Caldeira, K., 2010, Consumption-based accounting of CO_2 emissions: Proceedings of the National Academy of Sciences, v. 107, no. 12, p. 5687-5692.

General Comments

Several experts made suggestions for improving the effectiveness of DOE programs irrespective of the technologies involved, touching on additional questions posed by the framing document.

Better Data

Lee Schipper made a strong case that, "We need much more information than we have as a nation, given the diversity of climates, lifestyles, family situations that affect home occupancy day and night, home locations, and socio-economic situations of families." "Imagine if I went to the doctor for a diagnoses and took last year's urine sample, borrowed Rob Socolow's blood pressure and Arnulf [Grubler's] blood count and asked the doctor 'what is wrong'? That is about the state of what the U.S. knows about how its people and companies use energy."

Stability and Magnitude of Funding

Christopher Green argued "…that even more important than getting DOE allocations right is getting some year-in year-out assured funding for energy R&D, testing, demonstration." Similarly, Max Henrion stated, "DOE's current $4.3 billion annual spending on energy R&D, at only about 2% of the $200 billion global clean-tech spending, is unrealistic for a country that aspires to be a leader in many clean-tech markets. … If the U.S. decides it truly cannot afford to expand its energy funding, it would be wise to carefully select just a few areas where it can still hope to create a competitive domestic industry on which to focus its resources, and consciously cede remaining technology manufacturing to other countries. … The USA already appears to be moving along this path, allowing other countries, notably China, to win dominant market shares for manufacturing wind turbines and photovoltaics, as Thomas Friedman likes to remind us."

Technology Diffusion

Steven Hamburg stated, "[W]e do not know how to integrate new technology into broad use quickly (we do not have the systems to keep the trades current with the latest technology so implementation lags proven technology by decades)." Similarly, Vaclav Smil advocated, "A VERY LARGE chunk [should be allocated] for diffusing what we already know."

Specific Technologies

Following the discussion of factors the DOE should consider when allocating resources, Near Zero posed a second question. The purpose was to draw out more criteria by asking for specific allocations outlined by DOE under their six high-level strategies (**Fig. 1**).

Our instructions were: "For the next phase of this discussion, we would like you to imagine you have the power to allocate the $4.3B federal investment in RD&D as you see fit. Please allocate funds across the categories below as percentages, assuming you can also direct allocation within each category. (The categories below are taken from the QTR Framing Document)."

We also emphasized: "More important than your actual allocation are the factors that you used and how you applied them in your allocation. Please explain the factors you have considered and applied in making your allocation." They were also allowed to add additional categories and make comments on the taxonomy itself. To avoid bias we had participants send these allocations directly to Near Zero staff.

Several experts were uncomfortable with the requested exercise; we have included quotations to that effect below.

Ten experts completed allocations. Figure 2 represents their decisions, as well as the actual allocations in the DOE budget for 2011 as calculated from the American Energy Innovation Tracker.[1]

1 Energy Innovation Tracker is a database available online: http://energyinnovation.us/data.

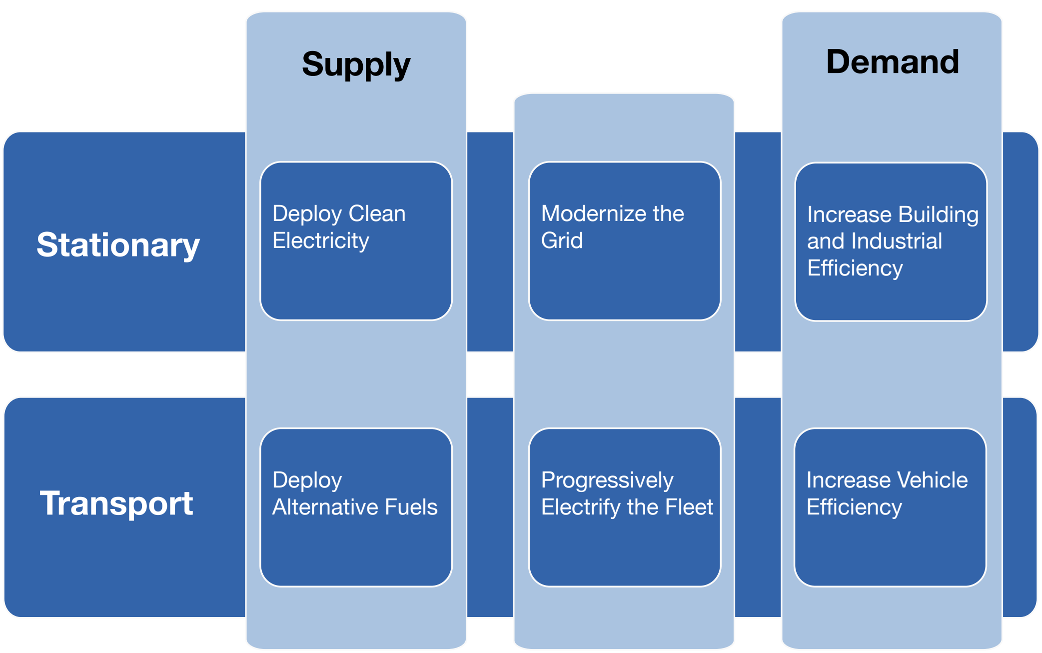


Figure 1. Taxonomy of DOE strategies as presented in the QTR Framing Document.

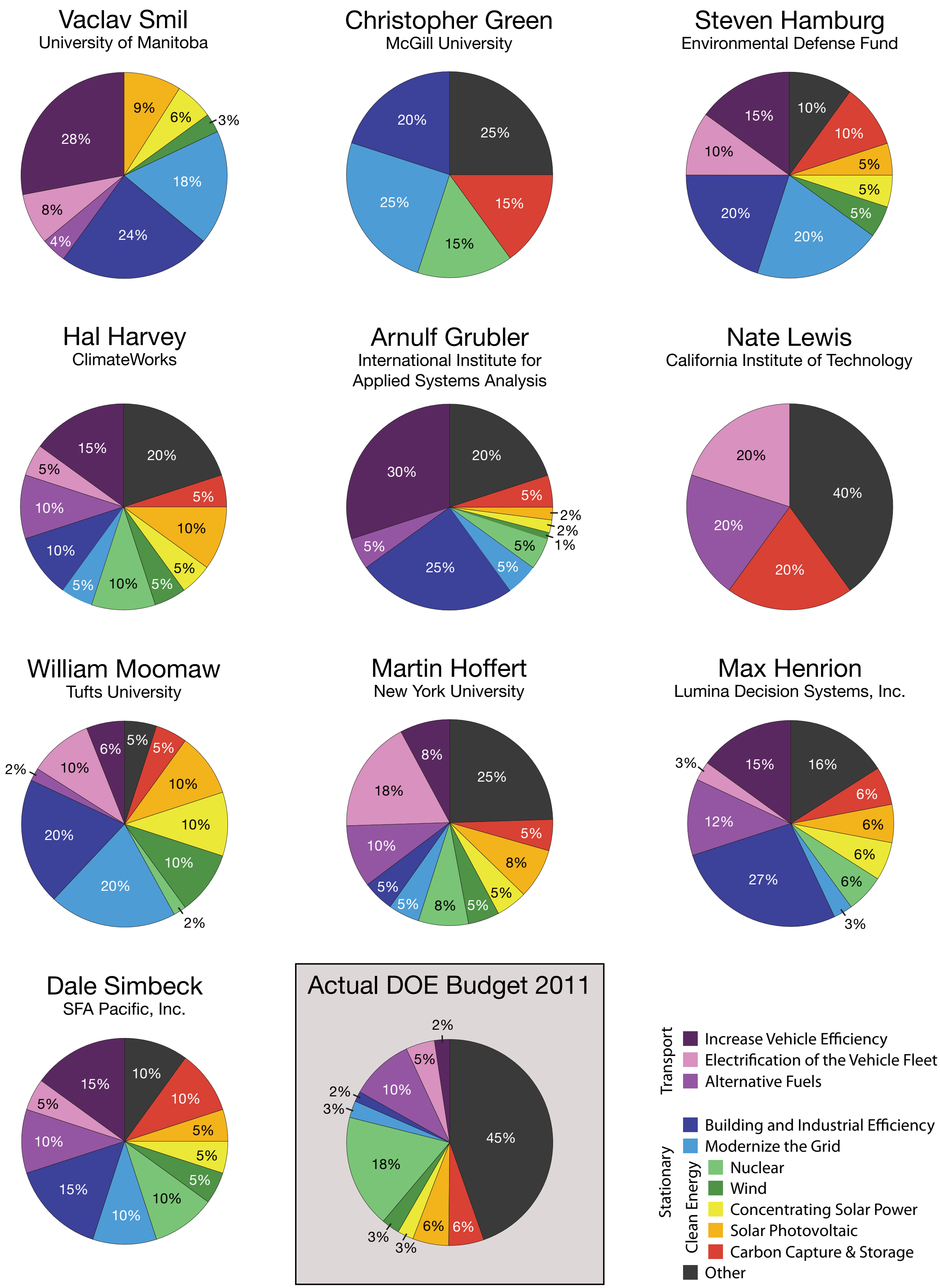


Figure 2. Expert allocations of the DOE budget among specific strategies and technologies. Actual DOE budget is shown for comparison.

Increase Vehicle Efficiency

Six experts allocated 15% or more to vehicle efficiency with most mentioning new and lighter materials (**Fig. 3**). Max Henrion (15%) explained that there is potential for “radically improved vehicle efficiency, including new internal combustion engine designs and lighter materials, as well as the more topical battery and fuel cell vehicles.” Similarly, Hal Harvey (15%) asserted that “lightweighting, [and] using advanced materials, can drastically cut energy use without compromising safety.” Martin Hoffert (8%) also mentioned “ultralight bodies and frames, composites, carbon nanotubes, power management, tires, roads, traffic & collision avoidance feedback.” Although Nate Lewis made no allocation to vehicle efficiency, he allocated resources to electrification of the fleet and commented, “electrification of the vehicle fleet means both light-weighting vehicles and better batteries and energy systems.”

In addition to vehicle efficiency, Hal Harvey again discussed the need for system optimization of vehicles, and described three categories:

1) “Price use of existing infrastructure: …New technologies can offer congestion pricing with low capital cost. The revenues from congestion pricing can be used to support alternative transportation modes. The DOE, in conjunction with the DOT, could consider the economics of congestion pricing in several cities, analyze the technologies, and suggest possible strategies forward.”

2) “Optimize complex transitsheds. Most U.S. metropolitan areas are served by between several and a couple dozen transit agencies. These systems are not optimized together—in routing, dispatch, maintenance, capital investment, or fare collection. The result of this is, predictably, slower and less frequent service and higher costs than necessary. The (DOE and DOT?) should develop system optimization software, and use it in one or two regions, to rethink and coordinate transit agency decisions.”

3) “Logistics have vast potential for optimization. Some fleets are well along on this front—per UPS or Fedex. But most urban fleets do not have serious optimization. Developing intuitive, public domain software for smaller fleets, and testing it in several markets, could have a large impact at a small cost.”

William Moomaw (6%) emphasized that “[vehicle efficiency] is essential for near term (5-10 years) reductions in oil consumption.”

In addition to Martin Hoffert’s allocation (8%) for vehicle efficiency, he created a new category which he called: “Transformative Transportation Tech” and dedicated 30% of DOE funds to it. Here Dr. Hoffert placed things such as “maglev, high-speed rail, smart cars & trucks, bike, motorbike, Segway and rolling roads integrated with rail commuting, computerizing transportation infrastructure, wireless electric power and recharge of cars and trucks from roads.”

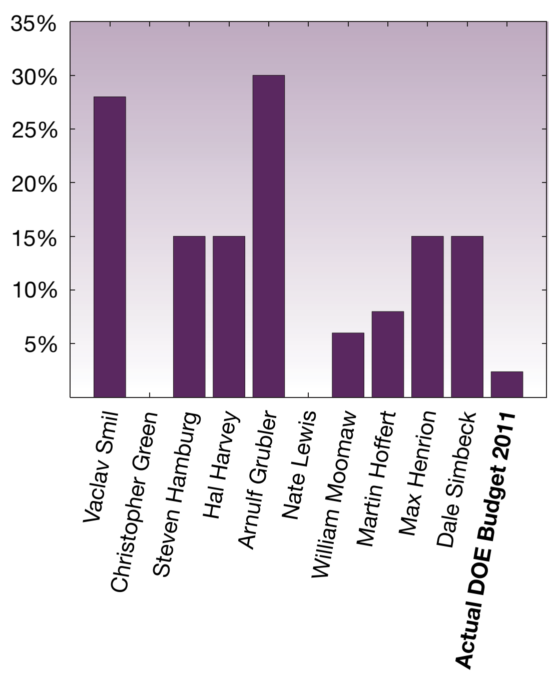


Figure 3. Percentages allocated by experts and the DOE to increase vehicle efficiency.

Progressively Electrify the Vehicle Fleet

Arnulf Grubler (0%) asserted that there is "...no basic R&D need for public sector, industry does already batteries." On the other hand, Nate Lewis (20%) took the position that we need "better batteries and energy systems which industry cannot now do because it is too risky." Martin Hoffert (18%) targeted "battery manufacture & ecology, motors, material recycle, power controls, catalysts, advanced batteries (particularly very high energy density lithium-air batteries)." William Moomaw (10%) stated that electrifying the fleet "…is the most viable option for a transformed low carbon transport system in the long term (10-20 yrs)."

Lee Schipper underscored the need for more use data, which "has profound impacts on energy demand and our energy future." There are "huge knowledge gaps" including the problem that "we have not done a survey of fuel use in cars since—ready—1985, when the same Reagan administration took the fuel-use diaries out of the then household energy survey as too much 'respondent burden.'" And in terms of trucks "we have no clue about how much fuel is used to haul a ton of a given kind of freight a mile, only some sense of aggregates for the major freight modes. … With cries for electrification of our auto fleet (cries I do not necessarily echo) we cannot make sensible predictions of who will drive what kind of car where and when it will be charged, or, in the case of a plug-in hybrid, whether it will be charged at all. We don't know how consumers will react to paying time of day charges for charging their batteries, not to mention whether they will pay carbon and oil taxes to guide their choices. Here there is a great need now for this kind of research. Toyota and other auto companies are doing some of it, but in my view too little now that the Leaf, Volt, and other key plug-in vehicles are launched or set to launch."

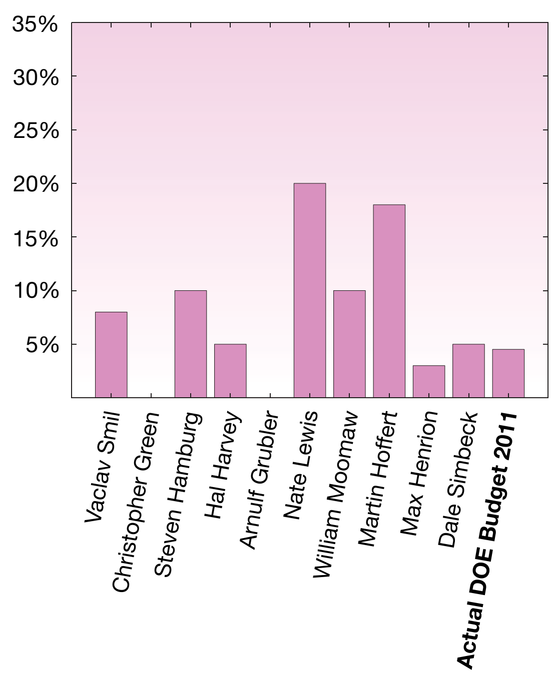


Figure 4. Percentages allocated by experts and the DOE to progressively electrify the vehicle fleet.

Hal Harvey (5%) raised the opportunity to optimize transport, surmising that "[as] vehicles become more complex (greater electronic control of engines, hybrid drive trains that can dispatch gas or electric motors, batteries that can be sized for power, or energy, and so on), the potential benefits of optimization grow enormously. The auto industry has relatively little expertise in this realm. Developing some tools to optimize across these dozen or so variables could reap large benefits."

GianCarlo Tosato was not comfortable with this allocation step, emphasizing that "systems analysis would be necessary in order to allocate RDD&D funds to demand and supply technologies based upon their contribution to achieve different levels of energy security, climate mitigation and economic competitiveness." Dr. Tosato's "complete list of observations and priorities based upon [his] experience and other non U.S. focused analyses" can be found in Appendix I. However, he would "not spend a cent on…electrification of the vehicle fleet, since it will happen by itself as soon as electric grids are smarter, distributed and with good storage capabilities, and vehicles more efficient."

Deploy Alternative Fuels

Participants mentioned the trade-off between food production and biofuels. Jane Long urged a focus on "technologies available for de-carbonized fuel that does not interfere with food production—i.e. fuels that are not dependent on biomass." Vaclav Smil (4%) seemed to agree, saying "NOTHING for any biofuels that use any arable land." Likewise, GianCarlo Tosato would allocate no money to "alternative fuels from biomass, because they destroy the food market." Lee Lane also mentioned "food scarcity resulting in part from ill-advised biofuels promotion policies."

A few noted the link between alternative fuels and electrification and that there should be an emphasis on strong carbon accounting. William Moomaw (2%) argued, "biofuels are very problematical in terms of net energy saved and the high fossil fuel input. Effort should be on algae, perennial crops and must be conducted with proper carbon and energy accounting." Nate Lewis (20%) stated, "alternative fuels are important not just for light duty vehicles but especially for aircraft, ships, and heavy duty trucks that essentially cannot be electrified. There would seem to be no option other than to use carbon neutral fuels for this process." Dr. Smil (4%) said "[Alternative fuels are] relatively a minor concern providing you succeed with [vehicle efficiency and electrification of the fleet]."

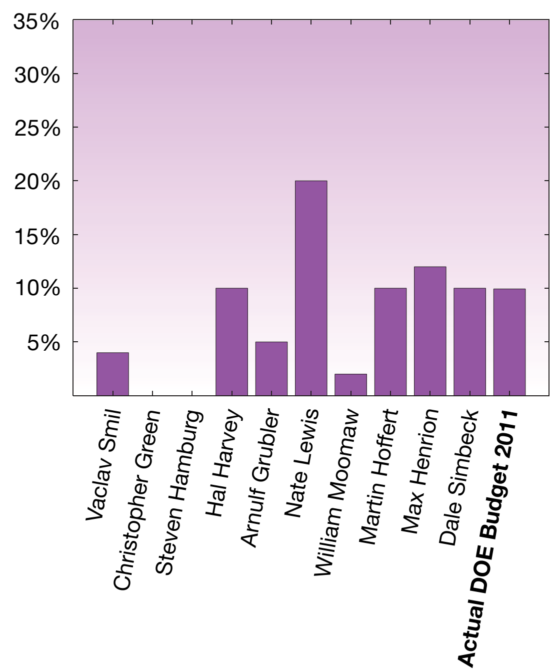
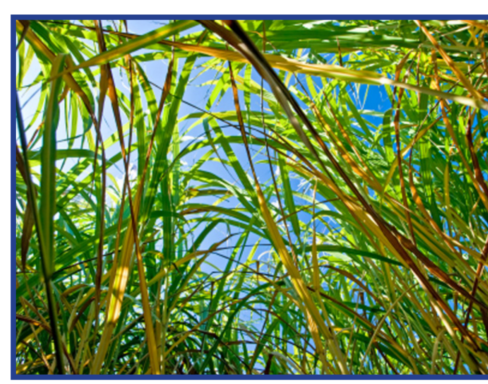


Figure 5. Percentages allocated by experts and the DOE to deploy alternative fuels.

Perhaps considering whether DOE funding is necessary, Jane Long said "biofuels are being worked very hard by venture money and the implementation problem will be a policy problem." Max Henrion (12%) took a somewhat different view, stating, "while the commercialization of cellulosic ethanol and advanced biofuels has been disappointingly slow in recent years, there are a wide range of promising technologies and improved sources of biomass. Some continuing support from DOE to supplement the extensive private capital is worthwhile. "

Martin Hoffert (20%) designated to "hydrocarbons synthesized from CO_2 for carbon-neutrality, algal biofuels & hydrogen for air and sea transport including cargo-hauling blimps & sail-augmented ships." Arnulf Grubler (5%) recommended "focus on 3rd and 4th generation biofuels and hydrogen."

Hal Harvey (10%) was cautious: "I am skeptical about [alternative fuels], and feel that electrification is not a panacea, but these need investment regardless, and I would hope to be proved wrong on both counts."



Increase Building and Industrial Efficiency

All but three of the experts participating in the exercise allocated 15% or more to building and industrial efficiency (**Fig. 6**). Arnulf Grubler (25%) recommended the DOE "focus on energy intensive industrial processes and cheap building retrofit efficiency measures." Likewise, Max Henrion (27%) believes "there is also potential for dramatic technology improvements, not just in materials and equipment, but also for fast inexpensive retrofit methods essential to reduce energy use in existing housing stock." Dr. Grubler wrote "…as a ballpark number: if we were to keep all supply side technology R&D as is currently, energy efficiency related energy R&D should be increased by at least a factor [of] 5."

Dr. Henrion (27%) mentioned job creation that would occur by spending on building and industrial efficiency adding "…there is tremendous scope for large savings…as well as green jobs."

William Moomaw (20%) mentioned the near-term of possible gains: "Building efficiency can be improved dramatically within the next ten years, and working with industry to improve industrial efficiency can bring large gains in energy productivity within a decade."

Martin Hoffert (5%) pointed out the need to solve non-technical barriers including consumer education and trial, concluding that it is "[t]ime to stop whining 'market failure' and do actual marketing." "Much good efficiency R & D has been done by DOE, not enough implemented. Emphasis should be on getting Americans to experience how advanced insulation, selective coatings, new lighting technology, smart grids with time-variable electric rate structures, passive heating and cooling, and the rest will impact architectures of entire homes, office complexes, factories and communities." Dr. Hoffert also posits "[t]he low-hanging fruit may simply be re-designed 'Victorian' piping and pumps to minimize losses."

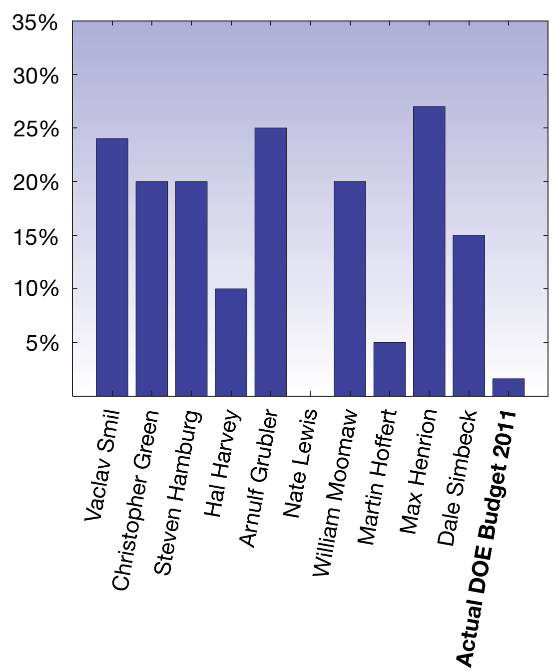


Figure 6. Percentages allocated by experts and the DOE to increase building and industrial efficiency.

William Moomaw highlighted missing data analysis and publishing. For example, while a house may be monitored by DOE "there are no funds to analyze the data or to publish any findings," adding that "monitoring and reporting of all DOE projects should be required if any of the successes are to be scaled up and if any of the mistakes are to be avoided."

A few experts also mentioned training. For example, Dr. Moomaw "…[argued] that one area of R&D should be to develop information and training programs for architects, engineers, contractors and building inspectors for buildings - and for engineers and managers of power plants and industrial processes and for manufacturers of vehicles." Dr. Henrion agreed that "…training for workers [is] key."

Dale Simbeck (15%) suggests the "DOE needs to focus more on energy conservation and efficiency even when it means major changes or challenges to existing politically powerful energy industries."

Modernize the Grid

Several experts stressed the importance of upgrading and expanding electrical transmission infrastructure. Vaclav Smil (18%) was blunt: “compared to Europe the country has no inter-regional interconnections and the grid looks quasi-medieval.” William Moomaw underscored that “…[modernizing the grid] is critical for utilizing renewable energy technologies and for having an energy efficient system for providing energy services such as transportation, industrial and building functions. This [strategy] should include storage and management practices.” Steven Hamburg (20%) noted, “[W]e have not begun to figure out how to manage the grid optimally (shed load quickly, base load represents the bulk of demand, feed back to users to reinforce efficient use).” Arnulf Grubler (5%) urged the DOE to “…focus on low cost underground electricity cables.”

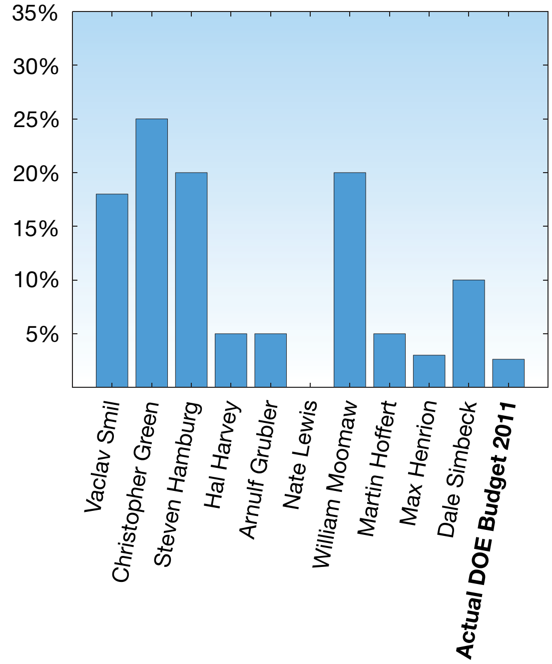


Figure 7. Percentages allocated by experts and the DOE to modernize the electrical grid.

Other experts saw the task of modernizing the grid as one of deployment not development, and thus questioned the need for much DOE investment. Although “…not comfortable with this sort of exercise” because it presupposes the establishment of criteria, Christopher Green assigned 25% to grid modification “…because it seems to me the latter should include substantial infrastructure costs (actual grid build).” Max Henrion (3%) agreed but reached a different conclusion, “This is important and there are a few areas requiring RD&D (other than energy storage), but the large expenses are for deployment and should be borne by power distribution companies because they are cost effective, so need for DOE funding is modest.” Martin Hoffert (5%) also urged DOE to focus on more radical R&D: “[L]eave grid power management including whether and where to switch from AC to high voltage DC for long distance power transmission, distributed generation systems, and perhaps smart grids to EPRI, who are closer to the utility industry, and focus DOE on transformative breakthroughs like whether we can implement something like Buckminster Fuller’s continental and global transmission grid, perhaps enabled by high-temperature superconductors.”

Deploy Clean Electricity

Nuclear

As might be expected, experts allocated a large range of resources to nuclear energy, from zero to 15% of the DOE budget. Vaclav Smil (0%) argued for no nuclear allotment because "it has already received 96% of all federal energy funding since 1948." Neither would GianCarlo Tosato fund "nuclear, because the original promise to be 'too cheap to meter' continues to be wrong, on the contrary it becomes more and more problematic, risky and unaffordable both economically and socially."

Arnulf Grubler (5%) advocated a "focus on safety and disposal, [but] NO new generation nuclear, [and] 0% for fusion." William Moomaw (2%) agreed that safety should be a focus, but allowed for research on "…distant technologies such as gas cooled and more inherently safe designs." Similarly, Hal Harvey (10%) recommended that nuclear funding be divided "…between (a) managing existing, including dry cask storage, decommissioning, ideally funded out of other parts of DOE, and (b) serious exploration of modular, smarter future technologies."

Martin Hoffert (8%) discussed new technologies in more detail: "The major problems of operational safety, waste disposal and limited availability of ^{235}U fuel to meet a 10 terawatt target by midcentury and beyond could in principle be addressed by (1) modular helium gas-cooled reactors (whose fuel pellets, not being water-cooled or water pumped, could not intrinsically suffer a loss-of-coolant accident like [Three Mile Island] or Fukushima); (ii) integral fast reactors (which among other things internally transmute long-lived actinides to less radiotoxic species) and (iii) thorium breeders (which burn ^{233}U bred from thorium -- in principle hundreds of times more abundant than the present reactor's ^{235}U whose identified resources and reserves have less energy than natural gas, and are hence likely to be depleted early on at a 10 terawatt burn rate). Small thorium underground reactors burning nuclear fuel that also addresses operational safety and waste disposal was proposed by the late Edward Teller and colleagues including the [Lawrence Livermore National Lab] Director are unfunded by DOE. ... DOE should be supporting RD&D in these technologies since they address real problems that must be faced to meet the President's goal which present fission program do not."

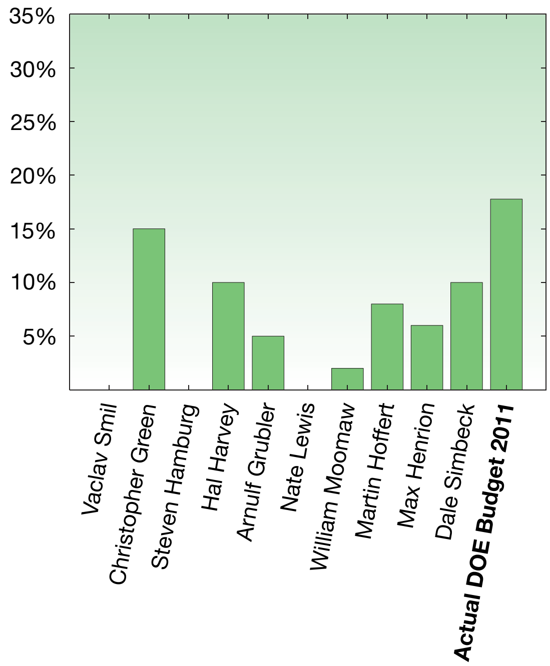


Figure 8. Percentages allocated by experts and the DOE to nuclear.

Wind

All respondents but one assigned 5% or less to wind energy. Max Henrion (0%) reflected the general opinion of participating experts that, "Wind power is maturing and commercially viable, so there appears to be little need for public R&D funding." Arnulf Grubler (1%) also said wind is "…mature, [and] only offshore upscaling R&D [is] needed." GianCarlo Tosato "would not spend a cent on... wind, a technology which became competitive against the official research and will now increase its market share where the grid [is] adequate." Martin Hoffert (5%) expanded on Dr. Tosato's mention of the grid, stating that, "The main problem of wind, like solar, is integration into the utility grid structure underscoring the issue of storage; although transmission is also an issue as the best winds apart from offshore are in the Great Plains. Wind turbines themselves are pretty close to their best efficiency." Vaclav Smil (3%) agreed, stating, "…no fundamental breakthrough can be made." William Moomaw (10%) saw a greater need than most: "[Wind energy has] [l]arge potential for making a difference soon. Need to find ways to lower costs and to deal with variability."

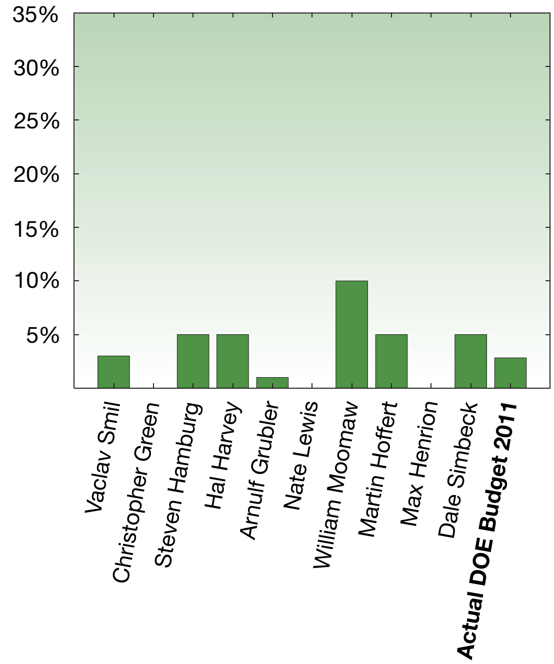


Figure 8. Percentages allocated by experts and the DOE to wind.

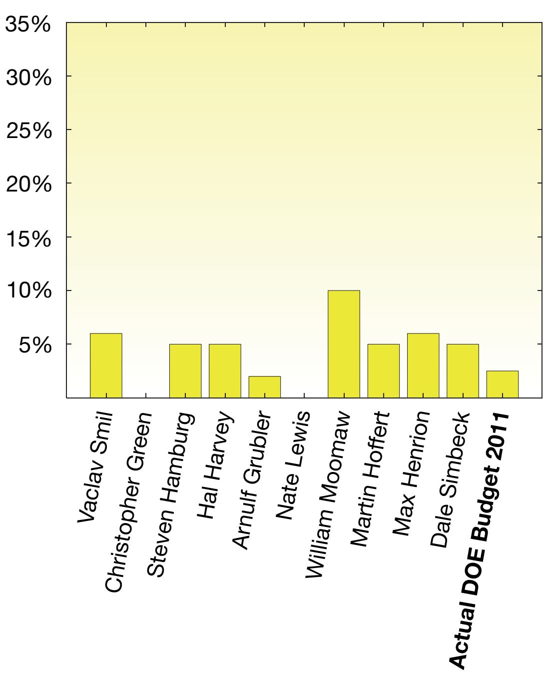


Figure 9. Percentages allocated by experts and the DOE to concentrating solar power.

Concentrating Solar Power (CSP)

Martin Hoffert (5%) disaggregated this category, saying "This subsumes two sub-technologies: Concentrators employ one- or two-axis sun tracking to focus reflected high-intensity sunlight at a focal point at which there are either (i) PV cells tolerant of high temperatures (e.g., GaAs) or (ii) tubes filled with a high temperature heat transfer fluid like liquid sodium conveyed to a heat engine to generate electricity. Priority should go to testing claims by advocates that the second approach, solar thermal, is more efficient than PV, and able to store significant energy in the bargain, as widely varying numbers are found in the literature." Arnulf Grubler (2%) recommended the DOE "…focus on energy storage, water minimization, [and] cost reductions." Similarly, William Moomaw (10%) emphasized "…[m]eans for cooing with little water, and for lowering costs."

Vaclav Smil (6%) asserted that CSP is "…a great adjunct to natural gas." In contrast, GianCarlo Tosato would allocate nothing to "concentrating solar power, because the potential technological improvement seems low and the storage potential advantage will be reduced with improving electric grids."

Solar Photovoltaic (PV)

Vaclav Smil (9%) remarked that solar PV is "…ultimately the best way to go in conjunction with all of the [other demand reduction strategies and energy supply technologies]." As for where resources should be directed, Martin Hoffert (8%) stated, "The main issue is manufacturing cost, moving rapidly down the 'learning by doing' curve, unless clearly more efficient or cheaper cents per kilowatt-hour photoactive layers can be found to the present crystalline silicon and thin film technologies. Again the limiting factor for the penetration of this technology at the mutiterawatt level is likely to be utility-scale storage." GianCarlo Tosato added, "solar PV seems still capable of 'learning by searching,' as well as 'learning by doing' [and] would allocate some funds to solar PV R&D and considerable support to the deployment of solar PV with carefully studied subsidies, to be reduced till the full competitiveness is achieved." Hal Harvey (10%) recommended that the DOE "…[p]ay attention, and put serious R&D money into balance of systems." William Moomaw (10%) seemed to agree, saying we "[n]eed to work on alternative technologies to silicon based technology to bring down costs with thin film, and new materials." Both Dr. Moomaw and Hal Harvey also stressed "[b]alance of systems cost savings." With respect to new materials, Arnulf Grubler (2%) mentioned "Low cost 'plastic' PVs."

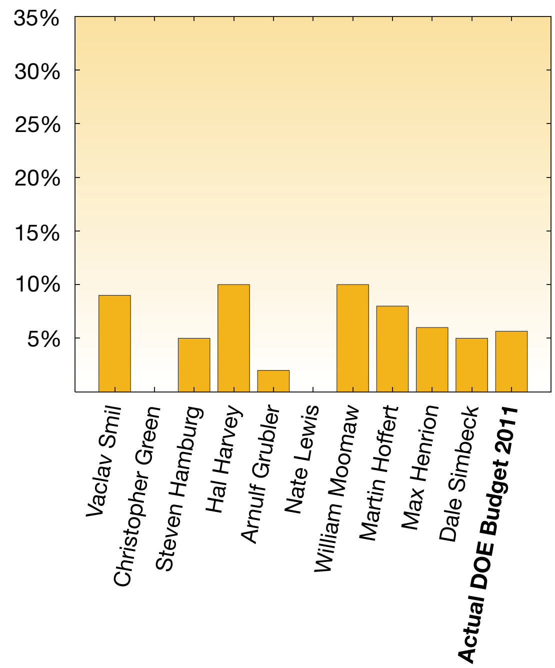


Figure 10. Percentages allocated by experts and the DOE to solar photovoltaics.

Carbon Capture & Storage (CCS)

Most expert responses emphasized demonstration of CCS projects. For instance, William Moomaw (5%) opined, "This is very long term, and we need to have demonstration technology to find the real problems." Martin Hoffert (5%) expounded, "As with other carbon-neutral energy technologies capable in principle of mutiterawatt electric power generation the immediate need is for full-scale demonstration facilities with which to test various centralized CO_2 removal technologies from coal-burning or coal-gasifying power plants. Long-awaited, the FutureGen experimental facility has morphed from the initial idea of CO_2 removal from a coal-gasifier fueling thermodynamically efficient combined cycle power plants with both steam and gas turbines and CO_2 centrally collected to its present incarnation as an oxy-fueled conventional steam plant burning pulverized coal in pure oxygen generated cryogenically to expedite CO_2 removal. This latter technology might allow cost-effective retrofitting existing coal plants for oxy-combustion and carbon capture and storage (CCS) though the economics are very uncertain. CO_2 storage R&D can be pursued separately and indeed is an ongoing commercial venture for the Dakota gasification plant whose construction dates back to Jimmy Carter's synfuel program. In any case we need real numbers for these processes and government underwriting research risk before industry will commit to this technology." Nate Lewis (20%) noted, "…[c]arbon capture and storage obviously needs work both in the research as well as demonstration, development, and deployment."

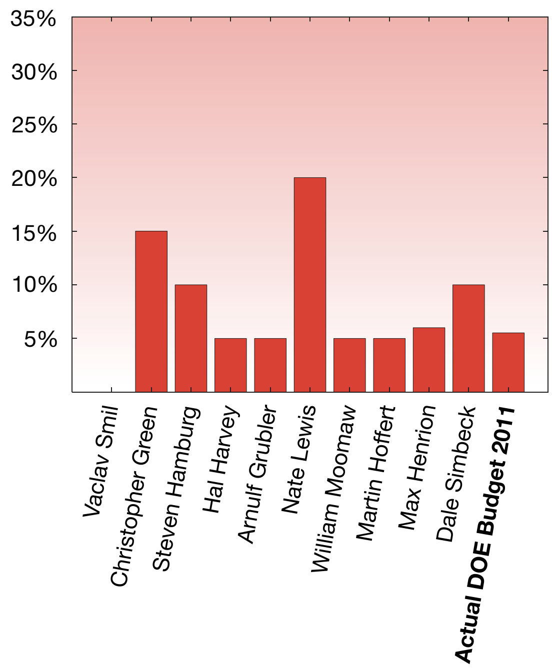


Figure 11. Percentages allocated by experts and the DOE to carbon capture & storage.

With regard to demonstration, Max Henrion (6%) chose to emphasize the necessity of DOE funding given the global scope: "Developing demonstration CCS plants is expensive, and has little hope of financial return until low-carbon policies are adopted. U.S. Government support is essential if the U.S. is to develop leadership in this area that is likely to be important for reducing world-wide carbon reductions, but it is only practical with a much larger RD&D budget."

Arnulf Grubler (5%) discouraged large-scale demonstration projects, saying that we should instead "…focus on learning from many small 'granular' CCS projects."

Meanwhile, Vaclav Smil (0%) simply asserted that CCS is "…a fundamentally wrong way to approach the problem."

Other

Utility-Scale Storage

Several experts brought up utility-scale storage as a key area for additional RD&D. For example, Christopher Green (20%) said, "Without breakthroughs in the area of utility scale storage, solar and wind will remain a relatively small part of the energy mix, and even then beyond a few percentage points will require maintaining adequate 'spinning reserve.'" Nate Lewis (20% to "renewable fuels and energy storage") agreed, explaining, "[E]nergy storage…is [an] enabling technology to compensate for intermittency, which is a key gap in our energy system." Likewise, Max Henrion (8%) said, "Efficient, cheap, large-scale energy storage is an essential complement for solar and wind if they are to become a large fraction of power generation. There are many promising, early-stage new technologies, and DOE funding should continue to accelerate progress. This area is wide open for innovative technologies, with the potential for growing a substantial domestic industry." Martin Hoffert also emphasized the immaturity of available technologies, saying, "[U]tility-scale storage…[is] the main hurdle to major market penetration of intermittent & decentralized terrestrial renewables, after the cost of the energy converters themselves. We have nothing commercially on the shelf, though compressed air energy storage, flow batteries and flywheels are potential options—pumped hydro not being feasible for most of the U.S. You can't even get reliable test data on the round-trip efficiencies of these."

Geothermal

Three experts allocated funds to geothermal energy. William Moomaw (2%) called it "[v]ery promising, but underfunded. Can be important in specific locations and should be addressed." Max Henrion (6%) went into greater detail: "Geothermal power has a chance (e.g. according to a recent MIT report[8]) of being a 'silver bullet' providing 10s or 100s of GW of consistent low-carbon base-load power at reasonable cost, an essential complement to solar and wind, and otherwise available only from nuclear power. There are large uncertainties about the extent of suitable geologies, the longevity of facilities, and possible association with earthquakes. Exploratory drillings and demonstration projects are expensive with a long payback period. So we won't discover its actual potential without extended public funding." Dale Simbeck also assigned 3% of the DOE budget to geothermal energy.

High-speed Rail

William Moomaw (3%) asserted that high-speed rail "can make a very large difference in reducing air and car travel in an electrified way that reduces carbon emissions in [the] next 20 years."

Space-based Solar Power

Martin Hoffert (10%) made a strong case for space-based solar power (SBSP): "It's outrageous that SBSP, which exploits the 24/7 availability of sunlight in geostationary orbit at 7 times surface intensity to collect sunlight and beam its energy to the surface by laser or microwave—invented in the U.S. by Peter Glaser in the late 60s and now being studied by Japan, China, Europe, Russia and India—has no DOE home or funding in the U.S. despite strong interest by some at NASA to test the beaming part from the International Space Station. DOE and ARPA-E managers have resisted even being briefed by experts on this technology which, despite fears of space weapons and prohibitive costs, is relatively safe in its infrared laser version and comparable for base load to terrestrial PV even today at present-day launch costs. Though space-based and ground-based PV are 5 to 10 times more expensive than conventional coal-generated electricity today SBSP could in principle power the entire world carbon-neutrally and is more near-term than fusion funded worldwide at $10 billion for ITER [the International Thermonuclear Experimental Reactor]. It is arguably the job of DOE to conduct innovative physically plausible research across a broad spectrum of alternate energies including this one to cut costs enough to achieve the President's energy goals."

8 The Future of Geothermal Energy, 2006: http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Energy System Integration

Martin Hoffert (10%) also urged the DOE to "[d] evelop and apply a new discipline, analogous to military or aerospace systems integration, for innovative & transformative energy options to design, identify and resolve critical technology issues. Without such tools, we would likely not have successfully accomplished the goals of NASA programs like Apollo, the Space Shuttle, planetary exploration missions and International Space Station, as well as countless weapons programs. [The] energy systems we must develop to meet the President's goals are at least as complex, and pose comparable challenges of technical virtuosity, as prior U.S. space and military technology triumphs."

Improving design and evaluation of an R&D portfolio

Similar to Dr. Hoffert's systems integration program, Max Henrion (2%) stated, "This exercise makes clear, if it wasn't already, that it's hard to design and evaluate RD&D portfolios. There are large uncertainties inherent in R&D outcomes and multiple metrics. The benefits occur in the long run and are contingent on public policies to price carbon and encourage low-carbon fuels, as well as the highly uncertain costs of oil and other fossil fuels. Figuring out the potential effects on the U.S. economy and jobs is still harder. Because of the complexities, our intuitions will be faulty. In such situations, exercises such as this by Near Zero and others, along with appropriate quantitative tools to explore scenarios and evaluate our assumptions can be especially insightful. Given what is at stake, the decision process should be careful and transparent. Decision analysts sometimes suggest that it's appropriate to spend around 1.5% of the budget at stake on allocating the budget. I have rounded up to 2% to reflect the challenges in this process."

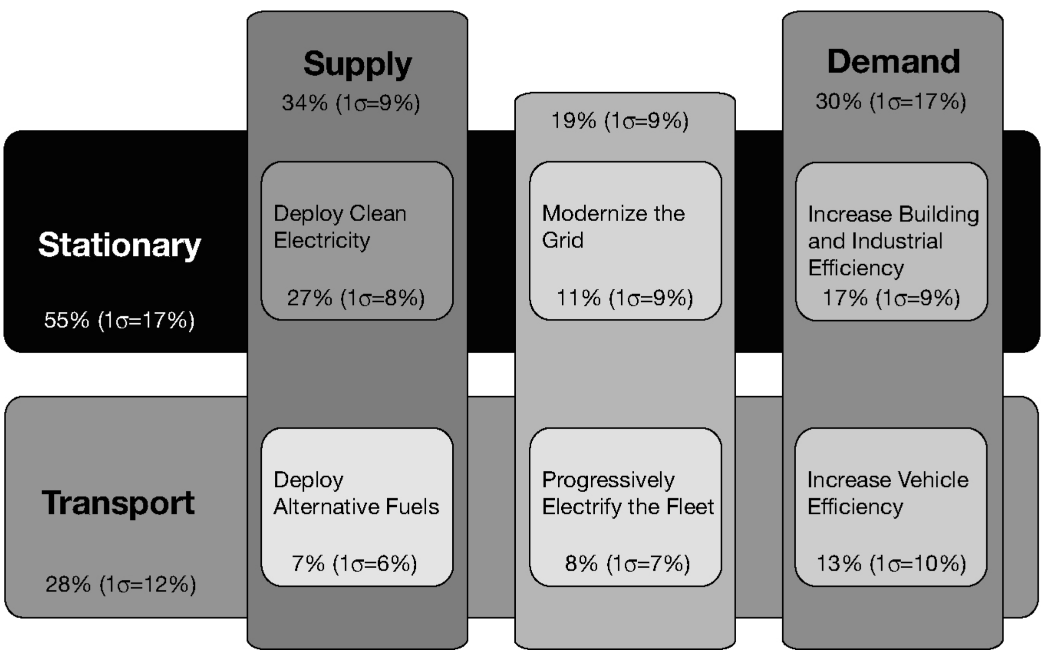


Figure 12. DOE's taxonomy of strategies shaded according to the mean percentages allocated by expert respondents in Near Zero discussion.

Appendix I

Transcript of Experts' Email Responses

Phase 1

Near Zero (David Keith, University of Calgary)
March 22, 12:31 am

Dear Energy-system Experts,

We are inviting you, as energy-system experts, to contribute to improving allocation of U.S. DOE energy RD&D dollars. We recently founded Near Zero, a nonprofit that aims to increase the frequency and value of dialogue between energy experts and those who make and influence energy-related decisions in government and business. Decision makers often lack credible, impartial and timely sources of information reflecting the range of expert opinion. What do the best experts agree on? When they disagree, what is the basis of the disagreement?

Steve Koonin, Under Secretary for Science at the Department of Energy, has invited us to provide input to the Quadrennial Technology Review in the form of comments to the published framing document (http://1.usa.gov/e2BiZP). We invite you to take part in a multi-stage discussion of how the DOE should prioritize the allocation of its resources among and within technology areas.

Near Zero will submit a summary of the discussion along with the complete discussion transcript, with attributions, to DOE by 15 April 2011. It will become part of the public record and be posted on the web. This will be the first of a number of discussions on energy that Near Zero will convene, moderate, and summarize. (Future discussions will make use of web-based tools we are developing to facilitate structured expert dialog, including tools to elicit and display quantitative judgments.) Our goal is to provide an efficient and fun way for you to leverage your expertise to advance decision makers' understanding of important energy issues. You are welcome to engage as little or as much as you like.

To begin, we would like your concise answer to the following question: 1. What are the factors that DOE should consider in allocating RD&D resources among technologies of disparate maturity and potential time to impact? At this point we are simply asking for factors that should be considered, such as "today's cost per unit output", or "achieved thermodynamic efficiency relative to maximum theoretical thermodynamic efficiency", "social acceptability", etc. Later, we will discuss how these different factors might be measured and combined to allow resources to be allocated more efficiently. Due to the compressed timeline, each phase of this discussion will take no longer than one week. Our goal is not to drive the discussion to consensus, but rather to clearly articulate different viewpoints and understand reasons for disagreements (e.g., different values [which values?], different perceptions of the facts [which facts?]).

Please either "reply all" to discuss broadly with your peers or send to doe_priorities@nearzero.org to respond to us alone. After we have received initial responses we will circulate a structured list (with attribution) to encourage an efficient group dialogue on priorities.

Thank you in advance for your participation.

Regards,
David Keith keith@ucalgary.ca
Ken Caldeira kcaldeira@carnegie.stanford.edu
Steve Davis sjdavis@carnegie.stanford.edu
Karen Fries kfries@nearzero.org
Brian Arbogast barbogast@nearzero.org
Jabe Blumenthal jblumenthal@nearzero.org

If you have further questions, please contact us; doe_priorities@nearzero.org forwards to the signers of this email. All comments will be considered part of the discussion to be published unless you explicitly ask for them to remain private. If you would like to be removed from the email discussion, please send mail (can be blank) to optout@nearzero.org.

Ken Caldeira, Carnegie Institution for Science
March 23, 5:21 am

As a non-expert in this field, I would guess you would proceed as follows:

If you had full information, you would design a cost function (i.e., maximization of NPV of GDP subject to some constraints [emissions?]). You would then develop curves showing how performance would change as a function of investment in each technology. You would then run an economic / energy model to see which pattern of investments optimized the cost function.

The problem is that we are making decisions under uncertainty and we do not know in advance those curves that would show us expected change in performance as a function of investment. So, we need to develop some sort of heuristics that would tell us when such investments would be likely to have high return.

It is difficult because it is essentially an economic problem, but the economic problem depends on our ability to make advances in science and engineering. Our ability to predict scientific and engineering advances I would imagine is pretty low, which suggests that risk reduction would weigh towards a broad portfolio. However, too broad a portfolio means investing in junk.

So, it may come down to assessing which technologies have little scope for improvement with additional RD&D, or which, even with improvement, have little hope of penetrating the marketplace. Are there metrics / heuristics that can tell us which technologies are likely to fall into these classes?

On the other hand, are there ways to tell which technologies might be able to provide more power at lower cost and lower environmental impact, if only there were a little more investment in RD&D?

Christopher Green, McGill University
March 24, 8:43 am

I am responding to the invitation from David Keith, et al, to comment on how the U.S. DOE might allocate energy RD&D funds. I assume in what follows that the main concern is with priorities for low carbon technologies that could be made sufficiently scalable that they can make an important contribution to stabilizing atmospheric carbon concentration at an acceptable level.

I think that to address the issue, which is framed in terms of priorities, it is first necessary to ask how big is the technology challenge to climate stabilization. As you know, In my view it is huge and it grows bigger as we reduce the stabilization threshold (e.g, from 550 to 450 to..., as Figure 3 of Hoffert et al (Nature, 1998) makes clear. Unfortunately, IPCC WG III in both the TAR and AR4 take a very different view: it says the technologies are available, although they may need some “commercialization”, no “drastic technological breakthroughs are needed, and that the main problem is political and socio-economic, not technological. I believe that the IPCC position is thoroughly wrong, and that its so-called findings are unsupported by the evidence. But many still believe the IPCC in this regard and that belief has stymied for at least a decade the sort of technology revolution required to stabilize climate. As a result, we still have no low carbon energies whose technologies are currently scalable on the scale required. Furthermore, the evidence mounts that without many major technology breakthroughs, the current low carbon energy hopefuls such as nuclear, solar, wind, CCS, considered individually or collectively, cannot come close to doing the job.

In this light, I think what is needed at the outset is a frank admission that the technological challenge and hurdles are huge, that priorities cannot be based on the hope for “silver bullets” technologies, and that a global effort is needed involving at least several technologically capable countries (including China, Korea, India, and Japan, as well as the usual Western suspects). No one country can go it alone. And breakthroughs will be needed on many energy technology fronts. In this context, individual national priorities might be based to some extent on national “comparative advantages” (e g., Canada, China and U.S. re CCS) and to some extent on the efforts of competing international consortia that pick technologies where they have an abundance of the needed scientific and engineering expertise. The main point here is that we need breakthroughs on many fronts and prioritizing should be done with an eye to what others are doing and what countries can usefully do collectively.

I also think we need to put to rest the idea that levying a carbon price (tax) will induce into existence the needed technologies. Much of what is needed is science driven basic research and development, followed by testing and demonstration of technologies that are (i) uncertain of success, (ii) if successful, are likely to provide payoff that begin only decades rather than years in the future, and (iii) have benefits that for the most part are not privately appropriable. The private sector cannot be induced to undertake such investments, and certainly not on the scale required, although some firms may be prepared to partner with publicly funded efforts.

Further, while a low carbon tax (say \$5.00/tCO_2) can provide plenty of financial support (~ \$25-30 billion/yr in U.S. alone), substantially higher carbon taxes are politically out of the question, and in the absence of sufficiently scalable low carbon alternatives brute force attempts to reduce emission substantially would be prohibitively costly. I would add that if effective carbon pricing requires some degree of “harmonization”, it is important to face up to what I might term the “coal problem”. As an example, while a \$30/tCO_2 tax is only 23 cents per gallon of gasoline (relatively small in relation to the price of gasoline---you can do the arithmetic per barrel of oil) it is \$85.80 per tonne of coal, an amount which is more than 100% of the \$15-65 price of a tonne of thermal coal at mine mouth. This example may help to explain why not only are technological breakthroughs needed to achieve scalability, but breakthroughs will be needed to assure at least a modicum of cost competitiveness.

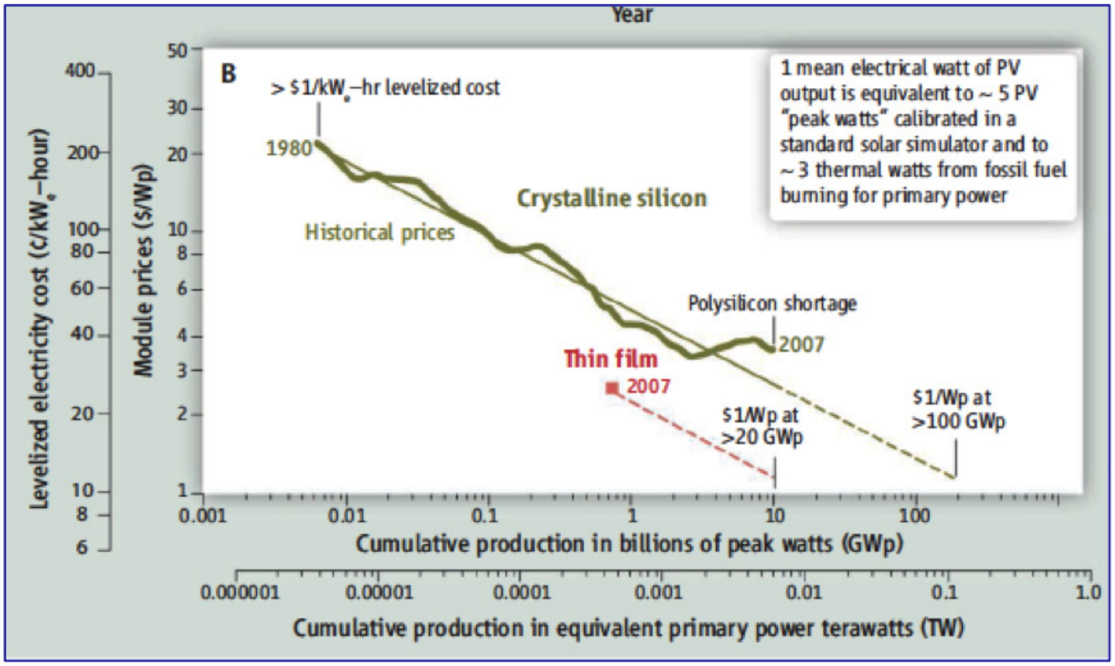
All this said, if in greater conformity with the question posed by Keith et al, I had to choose one technology that the U.S. (perhaps in consort with at least one or two other countries) should focus on it is utility-scale storage for (intermittent) solar and wind energy. Energy storage is a fundamental “enabling” technology, without which the effective contribution from solar and wind energy cannot grow much beyond niche proportions. I should add that here I am talking about storage that can retain the potency of the energy for weeks and months, not just the 8-16 hours that is possible with solar thermal. Furthermore, I am referring to storage that is both flexible and scalable in ways that pumped hydro and compressed air are not and almost surely cannot be. There are no short cuts here. Without breakthroughs in the area of utility scale storage, solar and wind will remain a relatively small part of the energy mix, and even then beyond a few percentage points will require maintaining adequate “spinning reserve”. Furthermore, I find implausible the suggestion that in place of formal storage a combination of overbuilding geographically disparate wind and solar farms plus “smart grids” can be an important means of facilitating large-scale storage for solar and wind. It is hard to believe that such a gerrymandered system could maintain anything like the grid and electricity on demand reliability to which we have become accustomed.

Martin Hoffert, New York University
March 25, 9:40 am

Wouldn’t it be terrific if there were a single objective metric to compare different energy technologies in an apples to apples way. An algorithm to just turn the crank every time a proposal comes in that would allocate scarce resources according to some optimization paradigm? I’m afraid we’ll have to make these decisions based on imperfect information, something an educated human mind still beat a computer or expert system at, particularly when we venture into uncharted territory, as innovative energy tech. We do have tools, and technology assessors and funders should understand them all and use them to the hilt where appropriate. The most important thing, as always, is asking the right questions. I hope we get into that presently.

For one thing, each primary energy generator and energy converter and energy storage device has unique physics and chemistry and metrics to go with them. Some of well-known ones are end-to-end energy efficiency, levelized cost of electricity, tappable terawatts of solar, wind, hydro, geothermal and ocean heat in nature; terawatt-years of nonrenewable energy feedstocks like fossil fuels, uranium, thorium and lithium on earth and helium-3 on the moon and gas giant atmospheres; pumped-hydro, battery, compressed air, flywheel and other energy storage costs in \$/kilowatt-hour per round-trip cycle, as well as their lifetime in numbers of cycles, power density of energy stores and converters in kilowatts per kilogram and for storage energy density in kilowatt-hours per kilogram and their cost in \$ per kilowatt-hour of storage. And once we get into the industrial ecology of alternate energy, recycling efficiency and costs of unconsumed but rare materials like platinum fuel cell catalysts, or neodymium for electrical motor & generator magnets, or cadmium, tellurium and selenium for certain thin-film PVs.

To project cost-variation over time, even with full knowledge that extrapolations are risky, we’d learning-by-doing curves like the following for PV module prices and levelized costs as a function of installed electric power generating capacity.



Unfortunately, economists don't have a great track record forecasting which technologies will break though costwise and which will hit unanticipated show-stoppers, or show-delayers, like Spiderman accidents on Broadway and Fukashima light water reactor accidents in Japan. On the positive side is Moore's Law for the exponential drop in microprocessor costs in large scale integrated circuits (similar to what is projected for PV above); on the darker side nuclear power projected in the '50s as becoming "too cheap to meter" became the most expensive electric power. The Shoreham never-operated-commercially light water reactor on Long Island (where I live), for example, designed to generate about 600 MWe would up costing $6 billion, or $10,000 per average kilowatt, about 20 ¢/kWe-hr not counting the fuel cost. PV modules today are cited by some as available at $2000 per peak kilowatt or also about $10,000 per average kilowatt at the busbar (not counting utility scale storage, if we're talking base load). So why isn't the Shoreham nuke, or PV, already making electricity on Long Island? Or offshore wind, for that matter, which it says here, is cheaper than solar albeit with a 25% duty cycle.

Shoreham never generated a single kilowatt-hour because there never was an acceptable evacuation plan in the wake of a nuclear accident like Chernobyl. This showstopper was discovered AFTER the decision. Okay, so some of my NYU grad students who were active interveners to stop Shoreham are pro-nuke now as the lesser evil compared with conventional coal. Ya live and learn. Ratepayers have to pay for it anyway ($2000 for every man, woman & child on LI). Just as we have to pay for wars based on at best bad intelligence and at worst cynical lies -- like the Gulf of Tonkin attack on the U.S. in Vietnam and Iraq having weapons of mass destruction -- with the rationale coming hundreds of $billions later that it was a good idea anyway.

The point I want to make is that technologies adopted for irrational reason often become locked in and very hard to dislodge politically, like Hyman Rickover's LWR design for the first nuclear submarine paid for by the U.S. navy becoming the prototype for 85% of the world's reactors (Chernobyl was copied from an even more primitive graphite "atomic pile" Enrico Fermi's team built under the U of Chicago squash courts in 1942.). Nuclear reactors, which are devices for making electricity or materials for nuclear medicine, are not a single technology any more than the Wright Flyer is the same technology as a Boeing 747 though both of them can fly. Now, as the world contemplates Japan's tsunami-triggered reactor accident, is a good time to realize that water cooled and moderated reactors dependent on pumps that can fail are not the best technology from a safety point of view. How did we end up with them? What was the optimization process? We should think hard about this.

And why is the U.S. DOE not, as China is, building demonstration plants of inherently operationally much safer than LWRs pebble bed gas cooled reactors <http://en.m.wikipedia.org/wiki/Pebble_bed_reactor>
or integral fast reactors with the the ability to consume and transmute long-lived radiotoxic products and thereby address waste disposal issues <http://www.google.com/search?q=integral+fast+reactor&ie=UTF-8&oe=UTF-8&hl=en&client=safari>?

And why do we have no plans for large scale demos of solar PV and solar thermal in U.S. deserts that can compare various ultility-scale storage ideas. And why no program at all in space-based solar, as Japan, the EU, India, China and Russia have, though the idea was invented here and many in NASA want very much to employ the ISS as a power beaming test bed. I don't say there isn't scattered interest in places like ARPA-E and some of the DOE Labs, but there seems to be no coherent way to assess the potential of these technologies to generate the 10-30 terawatts of carbon-neutral sustainable power to achieve the President's goal of 80% reductions in carbon emissions by mid-century.

There is a fundamental disconnect between that goal and the policies designed to achieve it, and we ought to be discussing that along with the metrics.

Lee Schipper, Stanford University
March 25, 10:45 am

Marty's response is intriguing. I have a different take on all of this

1. Relative to Marty's response, I hate to sound like an economist (I'm not formally) but only a economic framework allows us to get close to comparing apples with apples. What if one energy source really is low in CO_2 but high in cost (fuel cells from hydrogen made from electrolysis)? What if some energy sources have "elsewhere emissions" (from indirect land use, from battery driven vehicles)? There are many impacts, costs, benefits that have to be considered. Without an economic framework it is hard to compare these. And costs and benefits to whom? If we succeed in finding a low-cost way of taking the CO_2 (and other pollutants) out of coal at a power plant, do we ignore the families displaced if we dig the coal by moving mountains in w. Virginia that cover the coal out of the way? Recent LBL work suggested the externalities associated with energy are not that large-I don't disagree, but as long as we don't internalize them, demand is too large. And as long as we hide the cost of new energy sources or energy-using systems with "incentives" we never try to fit our demand to the costs of getting energy from those systems.

2. "Families" above should remind us about people, something DOE has been afraid to address since the brave work funded by Lynn Collins, who was a psychologist in the early days of EERE and supported Socolow's pathbreaking work on how real people heated their homes. Since then there has been a bit more of that kind of work, but I remember being laughed out of the Policy office for using the "L" - lifestyle - word to discuss work I had done when I was a sabbatical visitor at that small company on the south bank of the Thames, Shell International. "A No-No" I was told, even after the same briefing at Exxon the day before was actually packed.

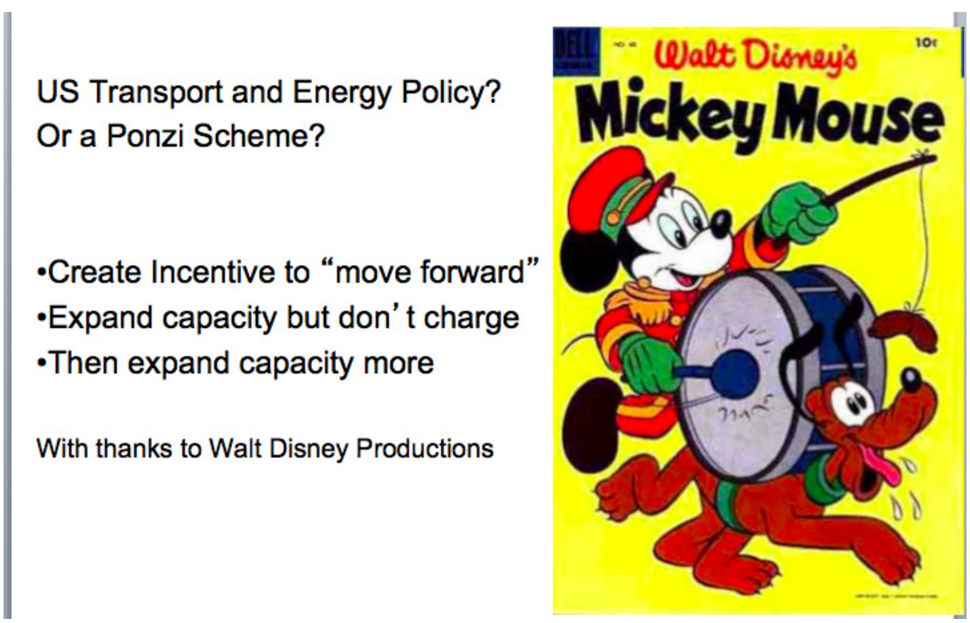
People use energy, people chose how to use technologies, and ultimately people (as citizens or within private or public institutions) pay for the energy they use. Yet the DOE technological focus seems to continue to treat energy technology as if we were putting a man or woman on the moon again. Technologies are important, but only if people chose to use them to produce energy, save energy, or reduce CO_2 emissions. A good example is from new cars sold in the U.S.. These get more than twice as many tonne-miles per gallon today as they did in 1980, surely a real measure of how much more we get from technology. But new cars and light trucks together only get about 35% more test miles per gallon today than they did in 1980, because fuel was and remains cheap. It still costs less, in real terms, to buy gasoline to run an average car/light truck on the road than it did in 1980-82, the peak years for driving costs in the U.S. (!). The point is we employed technology to boost car amenities, rather than save energy because energy didn't seem worth saving to most car buyers. So while I think it is important to explore technology, I see today's efforts as increasingly wasted as long as the national focus is so strongly on low cost energy, which is not the same as maximizing economic welfare (including environmental costs) from using energy.

The interaction of energy and costs is important. If Americans really had to pay for for energy, we'd learn to use it much more efficiently than with the improvements of the past 30 years. My paper with Scott Murtishaw (Energy Policy June 2001 -- happy to provide) found that roughly 60% of the decline in the ratio energy to GDP from 1960 to 1998 was because individual energy intensities (energy/passenger-mile, energy/$ of raw steel, energy/square foot/degree day of heating) fell. Some of that was hidden behavior adjustment (smaller cars, lower indoor temperatures in the winter, etc). The rest of the drop in energy/GDP was either structural shifts within sectors (less heavy industry lowered energy/output in manufacturing) lowering energy use, structural shifts raising energy use (higher shares of car and air travel and trucking), or intersectoral shifts lowering energy use relative to GDP (lower home area to heat relative to GDP, less domestic travel or freight relative to GDP). Is the efficiency improvement large? It could have been larger but energy prices did not rise so much, in real terms and adjusted for these improvements, energy costs did not rise so much, with notable exceptions like air travel.

The point is that if energy stays cheap because we chose to subsidize at the margin (ethanol subsidies, nuclear “incentives”, “Prius envy” (tax credits for hybrids and plug ins_) we run the risk of having to chase higher-than-otherwise growth in fuel and electricity demand with technology. If energy prices rise more because we end these kinds of subsidies demand growth will slow (“horrors horrors”) everyone will cry, but the whole problem is easier to solve. We’ll need less PV on our roofs, fewer square feet of solar hot water collector, smaller fuel cells or batteries to provide a given amount of range. etc.

In other words, what DOE research seems to lack is a few of how people will use technologies, and how the costs of those technologies might shape demand differently than we see it today. And DOE seems unable to examine what many of us think is inevitable - that truly low-emissions futures DO mean we’ll drive less than today (in part because we have to pay for each mile driven to keep the roads pot-hole free), we’ll have to stop subsidizing private housing size with the mortgage interest tax deduction etc. In other words, our tax and incentive system today fails to show consumers what homes and housing, roads and car use really cost, independent of energy concerns. So we have bloated homes and bloated cars with the highest per capita floor area and VMT of any wealthy nation. The same is essentially true relative to GDP.

3) These final points come from both a book I wrote in the m id 1980s on Swedish housing technology (with Henry Kelly, “Coming in from the Cold” , and one I wrote at the IEA in 2000 (with Lew Fulton, “The Road From Kyoto”). In each book a strong conclusions was that the energy problem in buildings was a buildings or transport problem, not an energy problem per se. Not surprisingly, in other countries the most advanced technology and policy work in these sectors is not driven by energy authorities, rather by public and private authorities attached to housing/buildings. If my previous considerations about how tax policy inflates our housing and travel sectorso are taken in to account this means that the energy “problem” - whether imports, local environment, or CO_2, is made worse by policies outside of DOE purview and outside of energy policies in general. So we are running on a treadmill or perhaps behaving like Pluto in the attachment (Courtesy of Disney Productions).



To sum up, I think energy research has to be embedded in a larger context of economics, people, and tax policy. Uncomfortable, yes, but maybe our inability to do that helps explain why we still have “cheap energy” and rising oil imports despite our best efforts to change.

Near Zero (Steve Davis, Carnegie Institution for Science)
March 25, 2:28 pm

Chris [Green], Marty [Hoffert], Lee [Schipper],

Thanks very much for your comments. Reading between the lines a bit, I hear a couple of main points being discussed:

1. The Criterion of Cost. Everyone so far has acknowledged that neither current or projected costs per unit energy are perfect criteria for prioritizing RD&D investments. Marty cites Spiderman accidents and the Shoreham plant to argue that uncertainty and lack of foresight undermine the criterion of cost. This is consistent with Ken Caldeira's conclusion that uncertainty of future costs prevents making decisions based on some cost function. Chris Green seems to agree, but not only because the success of a given technology is uncertain; he also believes the benefit of investments in low carbon energy (e.g., less climate change) will not be realized in the short term or--perhaps ever--by private businesses. Lee [Schipper] objects that, imperfect as it is, cost is our best chance at apples-to-apples comparisons, and implies that even social externalities like moving families in WV can be valued economically. Lee [Schipper] stops short of saying that a carbon tax could internalize the costs of climate change, but it would be interesting to he and Chris Green discuss whether such a tax could lead to low carbon technologies at the scale necessary to stabilize the climate anytime soon.

2. Path Dependence and Better Criteria. With reference to Hyman Rickover's design for a water-cooled nuclear reactor, Marty argues that where dollars end up flowing often has little to do with what is technologically optimal, but this only begs the question on what basis we should decide to go a new way? In the same vein, Ken Caldeira asks if there are metrics/heuristics that can help us identify technologies where a bit more RD&D could resolve whether technical barriers are surmountable and the technology has the potential to penetrate the market. So the question for Marty is, if RD&D is what is necessary for technologies like the pebble bed and fast integral reactors and space-based solar PV, then on what basis do we pick those technologies and not others? What about Chris Green's suggestion that we should be first and foremost concerned with technologies that can scale to "make an important contribution to stabilizing atmospheric carbon concentration?"

3. Demand-side. Lee [Schipper] makes the argument that we are stuck in an if-you-build-it-they-will-come mode, and that in addition to evaluating the technologies available for generating energy, we need to consider the incidence of energy costs. Regardless of technology, goals such as reduced emissions and energy security are more likely to be achieved without market distortions that prevent consumers from paying for the energy they use. Do others generally agree? Is there a criteria here for prioritizing investments in specific technologies or is this broadly applicable?

William Moomaw, Tufts University
March 25, 4:24 pm

Lee [Schipper] and Marty [Hoffert],

This discussion covers interesting ground, but let me try to add something to it.

Many years ago, Amory Lovins pointed out that people do not want or need energy, but rather "Energy Services." They do not care where their refrigerated drinks and air conditioning come from or where the heat to cook their dinner or warm their shower or home originates. Energy Services is an excellent place to start, yet DOE begins with a portfolio of energy supply technologies without considering how they will produce energy services. A version of the attached first powerpoint slide is being used to inform policy makers about the relationship among primary sources, energy carriers end use energy and energy services.

If one examines total primary energy supply and its extrapolation into the future one finds that the world is at about 500 Quads today, and IEA and others project reaching 700 Quads by 2030. The U.S. is using about 100 Quads/year of primary energy. Our end use energy consumption is only about one-third of that for energy services. But a quick look at how primary energy is used reveals that over half of it is deliberately released to the environment from heat engines - roughly 67% for fossil fuel electricity and over 80% for vehicle engines. See the second attached powerpoint figure from LLL. Note that this does not even address the inefficiencies in building use and industrial processes where reductions of 50-100%

are possible, nor does it include the potential to utilize waste energy (Bailey & Worrell). This implies that over half of all energy based Carbon dioxide comes form the waste heat of thermal conversions.

The reason that coal and oil are such huge shares of primary energy is that they are used so inefficiently in creating work. Of course nuclear power is even less efficient than coal plants in the conversion process. This has major implications. If we choose to keep on burning large amounts of coal and using CCS, and this exacts an energy penalty of say 25%, then it will be necessary to build a fourth coal plant to run CCS for every three coal plants built to produce electricity. This will increase the share of coal primary energy even further to produce electricity for energy services with more destructive coal mining, coal ash piles and acid mine waste , but carbon emissions would go down. But would the delivery of energy services to the user be any better?

Why not start with the end user, and ask, what energy services are needed, and which of those might best be supplied by say electricity. Then what are the lowest environmental and climate damaging options for doing so at the primary energy level? This should take into account mining, transportation, disposal of waste (e.g. Coal ash), air pollution, water pollution, health impacts and climate change. Here is where I agree with Lee [Schipper]: measuring economic damage costs is one good way to compare these otherwise incomparable aspects along with the direct economic costs of using a particular source and comparing it to other options. The new Harvard medical school study of the impacts of coal estimates that coal generates $500 billion in costs to society each year (Harvard). One can argue (and many will) with the methodology and assumptions, but they certainly have the sign right, whereas current policy treats all costs beyond those aspects that are regulated as zero. I have recently published a paper on nitrogen pollution and have used the economic damages methodology to compare diverse damages, and compared this with other means of setting priorities. There are some real surprises, and we recommend the use of multiple metrics (Birch et al). We are adapting this methodology to addressing the different environmental, health and climate costs of alternative energy technologies.

So if we need energy services such as light, electronics, refrigeration and transportation that are each well provided by electricity, then let us ask how those services are best supplied to end users cost effectively in a low carbon manner. In doing so, it is not only the cost of energy storage (where needed) but also transmission and distribution costs that need to be considered as well. These latter exceed our capital investment in energy supply today, and anywhere we can install distributed energy systems, we can avoid many of those costs. Building solar power satellites or Desertec in North Africa does carry some major construction and distribution costs.

Secondly, the United States is locked into a very bad case of “status quoism.” All of the 19th century fuels, and mid-20th century technologies are locked into place by laws and subsidies. Policies for years have discriminated and actively blocked new innovations. Every industry is at the federal trough for money. Note how much we have spent on nuclear power research and development, and yet, there is not a single example of a nuclear power project that has made it in a free market any where in the world. It is bound to government financing and insurance systems, which is a policy choice that we are free to make. Perhaps it is like ultra large scale hydro or space solar; “It takes a government…” When does it make sense to have heavy government involvement and when is it better left to the market place. The Danish wind turbine success suggests a very different approach than heavy government investment in R&D, and the importance of setting long term policies to attract investors to supply the technology.

How do we break the hold of the present technology to allow alternatives to thrive if they can? The current industries would have fought the shift from horses and buggies to cars and from gaslights to electricity. Fortunately those industries were too fragmented to know what was happening, and harness makers had to find new livelihoods. The U.S. has gone through a number of industrial transitions since then, the loss of textiles and steel to give but two examples. There is a process to innovation and industrialization, and we cannot hang on to what we had when its time has passed. That said, we can find ways to smooth the transition for those who are inevitable displaced by innovation.

To conclude, we only need about one-third of the primary energy we use today to deliver the energy needed for energy services at current end use efficiencies. That could be improved with solid research. Hence I would propose a research program that identifies energy service needs and compares alternative primary energy sources that might supply those services. There is a need to consider as Lee [Schipper] suggests the full range of social dimensions rather than to simply address the top down supply only approach that we have been following.

Let us remember that in 1975, ERDA and most energy experts predicted that Primary energy use in the U.S. would grow from 75 to 150 Quads by 2000, and that we would have 1000 nuclear power plants. In fact, we are right now slightly below

100 Quads and just over 100 nuclear plants. Somehow we have found ways to meet our energy service needs a whole lot more efficiently than the top down analysis told us we would need. We should learn from these historic examples and conduct a range of social, economic and technology research efforts starting with what are our true eenrgy service needs.

I hope that we can move constructively on this.

Bailey, O., & Worrell, E. (2005). Clean Energy Technologies: A Preliminary Inventory for The Potential for Electricity Generation. Berkeley, CA: Ernest Orlando Lawrence Berkeley National Laboratory.

Harvard coal study, 2011. http://environment.harvard.edu/news/general/new-harvard-study-examines-cost-coal

Melissa B.L. Birch, Benjamin M. Gramig, William R. Moomaw, Otto C. Doering III, andCarson J. Reeling, 2011, “Why Metrics Matter: Evaluating Policy Choices for Reactive Nitrogen in the Chesapeake Bay Watershed,” Environmental Science and Technology 45, 168-174.

Lee Schipper, Stanford University
March 25, 5:36 pm

[Bill Moomaw’s] note fits my point about the end-use sectors well. And buried in the almost forgotten AIP 1975 report on thermodynamics and energy. We can deplore the low 2nd law efficiency of space heating, but we design and build homes to leak heat and coolth with profligacy. We have improved, as I noted earlier but in my view the next 50% cut depends on architects, builders and occupants, not energy technologists. And the first importent building code in Sweden, SNB 67, never mentioned “energy” yet led to the least energy-intensive heating snywhere.

Christopher Green, McGill University
March 25, 7:47 pm

It strikes me that Bill [Moomaw] and Lee [Schipper] are writing about the U.S., while Marty is looking at the picture from a global perspective---as is appropriate. The great growth in energy demand in the 21st century will come from emerging economies and the rest of the developing world. Bill [Moomaw] and Lee [Schipper] are emphasizing energy efficiency improvements and using energy more efficiently to produce energy services. Improving energy efficiency is no doubt important but cannot come close to stabilizing climate. Consider the following:

1. In the 20th century global energy consumption increased 15 fold. With the very best efforts in improving energy efficiency we might keep global energy growth to a three-fold increase (2100 over 2000), and with a little slippage we are probably talking 4-fold.

2. A three-fold increase in global energy consumption over the course of the 21st century (we used 410 EJ/yr in 2000) while reducing carbon emissions by 75% means that we need upward of 1100 EJ/yr (~35 TW) of carbon emission-free energy (power) by 2100. (In 2000, we used ~60 EJ/yr [~2 TW] of carbon free power, 95%+ of which was hydro and nuclear.)

3. The focus on end use efficiencies/services by Bill [Moomaw] and Lee [Schipper] overlooks the huge amount of energy that is needed to produce the carrier of energy (electricity). The share of energy required for electricity generation is likely to grow, possibly substantially.

4. Lee [Schipper] seems to think that energy (or carbon) pricing can somehow bring about the energy technology revolution that I think is essential to supply 30TW+ of carbon-free power. In my earlier note I explained why relying on carbon pricing to induce the basic R&D, testing and demonstration of new, scalable energy technologies is fanciful. However, I think a low carbon price (say $\$5.00/tCO_2$) would be a very useful means of financing a technology-led climate policy, and if that low price gradually rises (say doubles every decade) would send a forward price signal todeploy new, scalable, cost-effective low-carbon technologies as they reach the shelf. But to put pricing first and technology second as Bill [Moomaw] and Lee [Schipper] seem to do is to put the cart before the horse

In short, I believe that as long as we think that the main answer to the climate problem problem is to raise the price of energy and focus on energy efficiency we will fail to face the energy technology challenge posed by any effective attempt to stabilize climate.

Lee Schipper, Stanford University
March 25, 8:36 pm

I agree that efficiency alone will not stabilize the climate. It just makes that feat much easier to accomplish, particularly on a global scale.

I believe in a carbon price along the lines of Stern $85/metric tonne of CO_2. That does not end life as we know it on earth (as a lot of hot air types insist) but defines something for efficiency, innovation, lifestyle adaptation, CCS etc. Without any carbon price at all we are up to the whims of a much higher growth rate in demand. I actually think we can manage a three or four fold growth in the 21st century if not lower. But the price of energy says a lot about what that growth rate will be, and the micro and macro economic evidence is pretty well irrefutable.

Much of the developing world is awakening at a time when we are much smarter on how to use energy. And we saw that when energy prices were controlled and low in China or India, some of the most inefficient industrial plant and equipment, not to mention vehicles and buildings, evolved. Remember that when we had the per capita incomes of the biggest Asian developing countries (1920s and earlier), the real cost of energy was higher and efficiencies were much lower and most of our home comforts (refrigeration, A/C, dishwashers) were just developing. The developing world doesn't need cheap energy and inefficient technologies to grow the way we did. they don't need cheap road fuels to feed sprawling cities like those in N America. Of course they could CHOOSE to feed that kind of growth, but that then increases their own energy, clean air, and water problems manifold.

We are not overlooking the primary energy requirements of electricity. If I cut the growth rate in electricity demand by 2/3 globally, I cut the primary energy requirements by at least that much, and probably by more, because we need less marginal electricity production at the higher primary/end use ratios of less-modern production. What Bill [Moomaw] and I argue is that energy services need to be affordable, and that the process of affording them adjusts the growth in demand for those services, the efficiency with which they are supplied and the primary energy behind that supply are important functions of energy prices.

If politicians and citizens don't want a carbon price, then I fear we fry. I do NOT believe we know how to finance a huge public sector carbon-free energy effort; we have failed in 40 years to finance meaningful advances from public funds in part because we are all politicians and want for ourselves, and in part because we have no experience managing a public sector fund to develop something that must compete in ordinary markets. We in the west failed in 40 years of "getting off oil" - we lowered the oil/GDP ratio markedly, largely because world oil prices rose now and then, but in part with fuel economy standards in the U.S. (but until recently not elsewhere). We still import lots of oil in the U.S. because clean substitutes tend to be more expensive, and because most governments do the bidding of the hydrocarbon industry and keep hydro carbon prices artificially low. So PV and many other potential energy resources, as well as nuclear (if that is still a resource) still are too expensive to compete with oil and gas and most of all coal. And if we cannot raise the price of energy before it ultimately raises itself, we cannot pay for the new sources. I do not believe R and D alone can make them "cheap" and I do not believe they need to be "cheap".

Remove prices from the equation and you have, well, much of the 40 years I have now been in this field, wandering around in an energy desert. Unfortunately too much of DOE focus has been on this magic technology, rather than understanding how people, economies, and technology evolve as we get smarter, richer, and one particularly small input, energy, is really more expensive than we want to admit.

William Moomaw, Tufts University
March 26, 7:30 am

Yes, Lee [Schipper]! We should not forget the AIP study of 1975. It sets an important standard for analysis that is based on basic physical principles that are all but forgotten at the analytical and policy level today. When was it last cited in an article in Energy Policy? If we ignore those principles, we will simply continue the brute force expansion of primary energy supply to meet the growing demand for energy services. Since particular services can be supplied with as little as one-tenth of current primary energy required today, and in many cases with zero carbon, I think we really need to rethink our approach in these terms.

As for buildings, Lee [Schipper] is right on. Five years ago I set out to build a zero net energy house in New England, which has winter days of -15F (even with current global warming). It took a major search to find an architect and engineer who understand how to do that, and a contractor willing to learn. Many things were “impossible,” but we did it, and moved in the summer of 2007. Super insulation and air sealing, proper siting, passive solar gain and daylighting, a ground source heat pump and solar PV. A lot of right sizing engineering produced a 2650 sq. ft. (U.S. average) house that uses just 6500 kWh for heat, domestic hot water, all lighting and a full compliment of electrical appliances. The house is grid connected, and sells about one-quarter of what it produces over the year to the grid producing a net surplus of about 500 kWh over what is imported annually. The house uses no fossil fuels, and just a small wood stove in the guest house, which uses just 0.2 cords annually.

The house is monitored by DOE through a subcontractor as part of the Building America program. However, there are no funds to analyze the data or to publish any findings. Right there is a cheap research proposal to DOE, expand these studies, analyze the data and make it available. In fact
monitoring and reporting of all DOE projects should be required if any of the success are to be scaled up and if any of the mistakes are to be avoided.

I would also argue that one area of R&D should be to develop information and training programs for architects, engineers, contractors and building inspectors for buildings - and for engineers and managers of power plants and industrial processes and for manufacturers of vehicles. The effectiveness of these programs should be monitored, evaluated and adapted to become increasingly effective over time. We could find only two contractors who had built an Energy Star House, which is specked to be just 15% better than code. One of them has now learned on the job with excellent supervision by the architect to build a zero net energy house.

Jay Apt, Carnegie Mellon University
March 26, 8:11 am

As I mentioned to the Near Zero team, there is a National Academies report that is relevant to this question: Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two), Committee on Prospective Benefits of DOE’s Energy Efficiency and Fossil Energy R&D Programs (Phase Two), National Research Council, ISBN: 0-309-66840-9, 234 pages, (2007), http://www.nap.edu/catalog/11806.html.

Excerpts follow.

“The primary effects of DOE’s programs are seen to be these: (1) they reduce technical risk, (2) they reduce market risk, and (3) they accelerate the introduction of the technology into the marketplace.”

“…analysts are a long way from having methods for valuing reductions in security threats contributed by technologies such as distributed generation. Recommendation 3: Panels should describe energy security benefits related to reduced oil and natural gas consumption quantitatively in the benefits matrix as physical quantities of oil and gas. The time pattern of the oil consumption impacts should be made explicit, along with an assessment of the probable state of the oil market during those future times.”

The NAS report evaluated programs on the basis of completion costs, economic benefits (cumulative net savings), environmental benefits (cumulative reduction in emissions), and security benefits (cumulative reduction in resource consumption). They used this results matrix:

Program Name:

Program Goals:

Year Goals Achieved:

Costs:

Current Funding Cycle:

Expected Cost to Completion:

		Global Scenario		
		Reference Case	High Oil and Gas Prices	Carbon Constrained
Program Risks	Technical Risk			
	Market Risks			
Expected Program Benefits	Economic Benefits			
	Environmental Benefits			
	Security Benefits			

Another resource that I've found useful is Third Generation R & D: Managing the Link to Corporate Strategy, Philip A. Roussel, Kamal N. Saad, Tamara J. Erickson, ISBN: 0875842526, Harvard Business Press, 1991. Summary: in 1st gen R&D, the insights and experience of tech managers determine investment, with no particular link to the organization's strategy. 2nd gen R&D measures project progress with respect to a set of goals and the project costs are compared to possible benefits to the organization. In 3rd gen, tech managers and the organization's top folks form a partnership to select projects aligned with the organization's goals and evaluate them, using a portfolio approach to deal with risk. The portfolio recognizes the differences among incremental (defends and expands current business), radical (drives new business), and fundamental (makes the organization technically competent as a leader) research.

With those two items from the literature noted, as well as the request to be concise, here are my thoughts on factors not necessarily covered above (I do like much of what is in the two sources I summarized), limited to my area of experience (the electric power sector).

Does DOE's investment have the prospect for solving a serious industry problem that is unlikely to be solved without DOE investment? An example would be acceptably safe storage of spent nuclear fuel. A second example would be reducing the number of transmission lines that are stability-limited by RD&D on active stability control.

A similar factor can be constructed for consumer problems. One of the factors that has encouraged resistance to smart meters (by customers) and smart grid investments (by PUCs) has been that neither is seen by the affected audience to solve problems they care much about, and both are seen to create problems or costs that the audience does care about.

Is the investment likely to bring costs to the range of other low-carbon power costs? This test applies both to deployment incentives (for example, does the learning curve require an unrealistic deployment level to intersect costs of other low-carbon technologies) and to research (are there fundamental limits).

Is the technology ever going to be important? For example, the amount of available tidal power for electricity generation is unlikely to justify DOE investment.

Will the investment increase American industry's global competitiveness? We sell wet flue gas desulfurization units worldwide in large part because our regulatory environment got there before the rest of the world's did. On the other hand, we are quite likely to be importing CCS technology, and probably Gen 4 nuclear technology.

Can the investment lead to increased innovation in the energy sector? This is not meant to be applied to all DOE investments, but can be useful (for example, microgrids may lead to such innovation).

William Moomaw, Tufts University
March 26, 8:54 am

I clearly did not make my points clearly judging from Chris [Green's] comments. We only need to triple primary energy over the 21st century if we start with an assumption that the delivery of energy services will come mostly through thermal conversions of heat to work. The delivery of energy services is not just a developed country perspective, but is even more important in developing countries where initial choices are being made as to just what those services are. There is now a robust literature on this. By starting with the need for energy services rather than extrapolating primary energy supply assuming current trends in primary energy use leads to carbon intensive future that is destructive of the opportunity to improve well being in developing countries and a major degradation of the economies of dev eloped countries.

One question that Chris [Green's] comment raises is if we are to advise DOE on research needs should these only be those that are for U.S. use or should we be more universal in our recommendations and include technologies that might be appropriate in other countries at differing stages of development? I prefer the latter, but would like to hear what DOE is asking.

Hal Harvey, ClimateWorks
March 26, 3:29 pm

This is getting interesting.

May I offer three thoughts: (1) Our remaining carbon budget does not allow us the luxury of choosing between efficiency and low-carbon supply technologies—so that debate is beside the point; (2) There are three approaches to policy: a) performance standards; b) economic signals; and c) R&D. They are highly complementary, and none can do the job alone. The sooner we get past the religious preference for one over the other, the better; and (3), to the original question, some suggestions about "What are the factors that DOE should consider in allocating RD&D resources among technologies of disparate maturity and potential time to impact?".

BTW, it would be nice to move this to a structured web page of some sort so we can separate the threads and link other materials to the conversation.

(1) Efficiency v. Low Carbon Technologies.

To stabilize at a reasonable ultimate concentration of CO_2, we need to do two things: (1) Invent the technologies and the social/economic/political practices that spread the technologies of a near-zero carbon economy, and (2) make sure we don't bust the carbon budget on the way there. CO_2 has very long residence times in the atmosphere, so if we spree over the next fifty (or even 25) years, we have no chance of stabilizing at a reasonable number. (OK, there are two chances: Shut the whole economy off, or invent extremely cheap negative carbon technologies. Neither is likely and the former is not desirable.)

Our budget for carbon to stabilize at 450 ppm is about a trillion more tons of CO_2. That's cumulative. [Apologies since I am in a plane, w/ no access to the internet and a flawed memory, so these numbers may need calibration.] Today the world emits around 50Gt/year. With no growth, we use up the entire carbon budget for a 450 ppm world in 20 years.

Obviously, we need, now, to stop waste. (If this is not obvious to you, google "climate interactive" and play with a CO_2 concentration model. It is very enlightening. We are supporting this team to expand the model so that you can play with energy technology assumptions and get CO_2 results. Very useful for debunking all of our prejudices (and for scaring oneself!).) Aggressive deployment of ever-more efficient cars, houses, and factories is the only way that low carbon technologies can catch up with economic growth, and then displace existing power and fuel supply. The only way. Note also that innovation works brilliantly in the efficiency space, and that progress will compound when we finally get around to working on system efficiency as well as device efficiency.

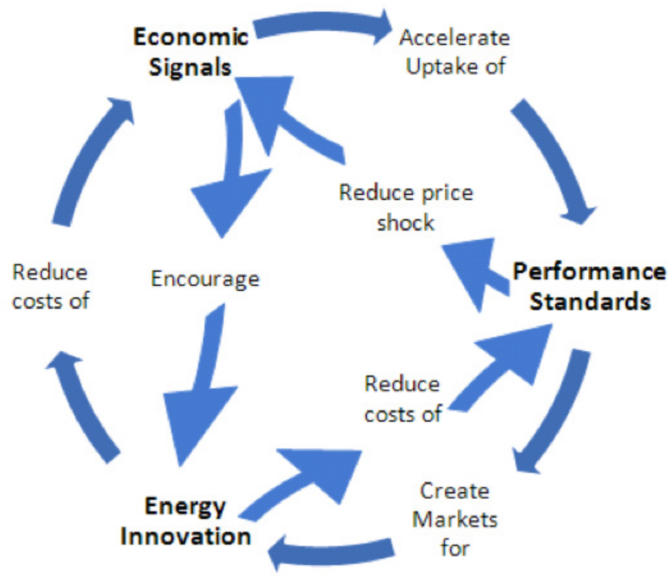
Sonia Aggarwal and I have a paper coming out on this soon.

(2) Policy Choices

It is fashionable to argue that an economic signal (tax, cap) is the most efficient way to deal with carbon, and that pricing is a single point solution. It is also wrong. The truth is that performance standards have been by far the most effective method so far of reducing energy waste and bringing in new technologies. Building codes, fuel efficiency standards for cars, utility RPS, appliance and equipment standards actually get the job done. Because of well-documented market failures, carbon pricing is a lousy way to reach many sectors.

But carbon pricing works well for some actors and for long term industrial decision-making, and it is a highly useful complement to performance standards. The truth is they need each other.

And both also need innovation, including directly funded government R&D. Innovation makes performance standards easy to meet. Innovation makes economic signals have a big impact at affordable prices. Here is a snapshot at the interaction of the three:



Also attached is an excerpt on the topic from our 2009 Annual Report. Do these three right, and dramatic changes happen.

(3) Finally to the original question: What factors matter?

This is a complex set of questions, really, so here are some quick jump-start suggestions:

- Pursue technologies that are not near their thermodynamic asymptote. Motor efficiency is not especially interesting any more. Pumping systems (including piping size, coating, bends; electronic throttling instead of mechanical valving; and of course motors) is extremely interesting.
- Pay attention to raw materials constraints. Wind may never get much cheaper than 7 cents/kwh because of the raw materials costs of towers and blades. (Mind you that's a great price!).
- Open up the treasure chest of system efficiency. Optimizing devices only gets us so far. Optimizing systems is really interesting. Think PV plus building materials. Lightweighting and the virtuous compounding on every component of a car. System optimization is the key to making renewables cost effective well before storage gets cheap.
- Pay attention, and put serious R&D money into balance of systems. We lose if we have very cheap, very efficient PV bolted onto expensive, one-off, inefficient racks, inverters, and so on.
- Focus special attention on promising technologies where there is no obvious market maker. There is no industry really organized to make CCS happen—so it keeps not happening. Ditto truck efficiency. Advanced biology. And so on.
- Focus special attention on technologies with billion dollar stair-steps in their learning curves—since the market ignores these. See www.americanenergyinnovation.org for a discussion.

Lee Lane, Hudson Institute
March 27, 8:22 am

Responding to the invitation from David Keith to comment on U.S. DOE options for allocating energy RD&D funds, I offer three broad suggestions.

First, Arrow, Nelson, Rosenberg, and many other students of the economics of innovation have noted that institutions act as powerful filters in the process of technological change. Current institutions and related factors of political economy are such that most countries will reject any but the very lowest cost measures to curb greenhouse gas (GHG) emissions; hence, measures like CCS that are inherently costly and lack all purpose other than GHG control are quite unlikely to be widely used. Certainly, countries like China and India, where they would be most useful are likely to spurn them. Such technologies, therefore, should be relatively low on the list of R&D priorities. In other cases countries, measures that claim GHG control benefits but which are in fact mere pretexts for rent seeking. By their very nature such policies offer little benefit compared to their costs. It makes little sense to throw public R&D resources into making incremental improvements in wind turbines and other technologies employed in such schemes.

Second, proper division of labor between public and private sectors is vital. For technologies that have, or that purport to have, commercial value, government spending needs to stay well upstream of commercialization. To do otherwise squanders scarce public sector funds on projects that can, if they do indeed have merit, eventually attract private sector investment; worse, it starves more basic research of the public funds without which they may not take place at all. The need to hoard funds for these investments is all the more pressing given the prospect of long term fiscal stringency. Further the closer a technology is to commercialization, the more likely it is that the process has been captured by rent seekers. The systemic problems that have plagued DOE demonstration projects suggest that this problem is deeply rooted, in part in Congress and its members' incentives. Thus, the question of what stage of the R&D process at which public funding should cease is at least as important as the selection of specific technologies. Earlier is better.

Third, the prospects for global decarbonization are so distant that it may be useful to set priorities with more diverse public goals in mind. Greater capacity for the genetic modification of plants would, for example, be of much value in adapting to some aspects of climate change as well as helping to offset the food scarcity resulting in part from ill-advised biofuels promotion policies. The same set of tools may also contribute to the more rapid exploration of algal fuels; again, an option with benefits ranging far beyond narrow concerns about GHGs. The point is not that the public sector should be developing new plants or algal fuels. Private firms that are much better at reading and predicting market trends are already engaged in those endeavors; rather, DOE's focal point should be to enhance the scientific knowledge, tools, and techniques employed by others in the pursuit of more fuel and food. I personally lack the expertise to be specific about research targets. People in the field with vastly more knowledge than mine, though, seem to be saying that adding more federal resources in this area might speed progress. If DOE's investigation bears out these claims, this area is one in which the Department has scored important past successes and presumably one in which it retains some expertise. The fact that the research areas may offer potential payoffs whether decarbonization is slow or very, very slow adds an appealing aspect of hedging to the play.

I hope that these thoughts may be of some use in your important deliberations.

Dale Simbeck, SFA Pacific, Inc.
March 27, 10:47 pm

The only thing I know for sure is that DOE is getting very poor value out of massive amounts of money it is spending on Energy Technology.

A few simple but very important thoughts:

1. High USA carbon (or CO_2) taxes simply trash our economy unless we place the equivalent tax on carbon produce in production and shipping of imports. Economically forcing carbon intensive industries to move production from the USA to China (which is much higher coal-based energy) just increases world CO_2 emissions while hurting our economy. Ken Calderia did the attached nice paper that addresses imported product indirect carbon emissions. [Davis and Caldeira, PNAS 2010]
2. The only carbon and CO_2 mitigation options that do not hurt our economy and reduce our economic competitiveness are conservation and efficiency. Sadly, these key options are just superficially talked about in most reports without addressing the big challenge required for the big gains. Conservation and efficiency is marginalized to simple options (like florescent light bulbs) to avoid disruptive changes in big established industries. For example, there is a lot of potential in improved construction and especially construction materials to conserve energy in both the building energy consumption and energy consumed in making the building materials. However which would increase building costs by about 10% (to save up to 60-80% of building energy use) and require building material specification changes to reduce use of high energy kiln products building material. Check out a group call Calstar wanting to make non-kiln fired bricks. However, the biggest efficiency gain is replacing old 30-35% efficiency coal power plants with gas turbine based NGCC cogen. The key is being able to sell high efficiency cogen electricity into the grid at a fair price. That is the U.S. electric utility industry's worse nightmare. They effectively marginalize this by claiming the industrial cogen market is already saturated (not true when cogen based on back-pressure steam turbine are replaced 5-10 time higher power-to-cogen heat ratio gas turbine based cogen) and promote cogen for just small distributed generation (as this is too small and uneconomical to impact utility power gen).

3. The current ideas on carbon or CO_2 taxes are too low to force most of the USA's 300 GW of old paid-off coal power plants to do anything but simply add that tax to their coal plant power prices. A much better approach is the proposed Canadian option attached to force shut-down once 45 years old.

4. Attached is a very insightful report by Brattle on the regulated electric utilities likely response to EPA proposed "end game" to add onerous emission mandates to help force replacement of old dirty exiting U.S. coal power plants. We do similar analysis for our clients but they are client private. The key issue is that IPPs will replace old coal units with NGCC while the regulated electric utilities will make stupid retrofit investments in their old coal power plants instead of replacing them with much more efficiency alternative like NGCC. This is because the big dog regulated coal electric utilities know they will get nice returns on these new retrofit investments and more importantly, will still have lower power costs that any new cleaner and much more efficiency coal or NGCC power plants. Maintaining low power costs are key to keeping competition for IPPs and especially industrial cogenerators at bay. Always remember PUC regulators get re-elected purely on keeping electric power rates low. Paid off coal units even with new retrofit capital charges are still cheap and the economic marginal load dispatch costs (exclude capital charges) are much much cheaper than any NG based power gen.

These comments may not direct apply to DOE's Quadrennial Energy Technology Reviews. Nevertheless, DOE needs to focus more on energy conservation and efficiency even when it means major changes or challenges to existing politically powerful energy industries. Even worse, DOE must quit protecting status quo by focusing too much of its R&D funds on the advanced clean energy technology of the future, forever. Range Fuels is a good example that we knew would fail years ago, long before one third of a billion dollars was wastes on it (half Gov. money). Advanced energy development is much harder than high traditional tech developments because the new energy tech products must replace established energy producers and technologies with paid-off systems discussed in my attached presentation.

GianCarlo Tosato, International Energy Agency Energy Technology Systems Analysis Program
March 27, 10:49 pm

Since my collaboration to the preparation of the IEA Energy RD&D Group Strategy in 1980, I've been busy with these problems. Thanks for including me in this experts panel.

This consultation envisages two ingredients of the classical Delphi method: a multi-stage discussion and a structured expert panel. As customary in the procedure of this method, I prefer to address my considerations directly to the group of facilitators. Any elucidation of the procedure you intend to follow will help me to understand your method and I think in general will add credibility to your concluding remarks.

You invite me to debate 'how the DOE should prioritize the allocation of its resources among and within technology areas'. As far as I understand base research is excluded from this discussion. In my opinion this implies that we keep out of the picture 'silver bullets' or any brilliant scientific-technical solution to the energy problem, similar to the cell phone for voice communication services or internet for communications in general.

As the Nobel Prize-winning economist Arrow demonstrated in 1963, it is impossible both democratically and consistently to aggregate individual preferences in a plural society. Therefore I like the fact that your 'goal is not to drive the discussion to consensus'; it also means that technological controversies are accepted. [And in fact Andrew Stirling verified that any possible ranking of energy technologies is present in the literature.] In order to take into consideration the most important such controversies, I suggest that you check whether the 62-expert panel represents in a balanced way energy producers and consumers in all energy supply and demand sectors. Sometimes consumers tend to be less represented in the energy debate. If necessary I suggest that you integrate the pane with additional experts. When you will make publicly available the affiliation of the panellists, if the participants appear representative and independent, the indications of your final report will be more robust.

Like some other addressees I'm not a U.S. citizen. I interpret the international composition of the panel as an intention to consider the global nature of the energy technology system and of the climate change problem, along with the more domestic dimensions of security and competitiveness.

Your email and the reference DOE document assume a quite extended view of the energy technologies system. The complexity and extension of the global energy system, as I view it, is schematically represented in chart 1. This helps understanding that no energy technology works in isolation: complementary technologies & commodities form chains, substitute technologies and their chains form a system. It is therefore necessary to use systems analysis, which "applies systems principles to aid decision makers in problems of identifying, quantifying, and controlling a system, while taking into account multiple objectives, constraints, resources, it aims to specify possible courses of action, together with their risks, costs and benefits." (quoted from Principia Cybernetica). In my opinion, technologies can be best ranked taking a broader system view and evaluating them "in the same playing field".

Since this 'discussion' is intended to guide the decision of a public body such as DOE, I assume that long term consideration prevail over short term ones, and the value of public goods which do not have a market price is included in the picture. Short term economic and financial considerations come afterward, when the DOE has to implement the priorities in a market economy.

In order to better understand your question n.1 'What are the factors that DOE should consider in allocating RD&D resources among technologies of disparate maturity and potential time to impact?' I checked the meaning of the word factor. According to the Webster's New World Dictionary, 'factor applies to any of the irreducible component parts or principles that are instrumental in determining the nature of the complex'. Interpreting here complex as the global energy technologies system, I interpret the expression 'irreducible components as aspects given by different branches of science.

In my opinion the main quantitative dimensions of the energy technologies system and its future behaviour are the 4E: Energy (including security), Engineering (including learning), Environment (including climate changes), and Economy (including sustainability). Other important mainly qualitative dimensions are: social, political, administrative, safety, etc.

Field experts in each scientific branch contribute to characterise possible future developments of each supply and demand energy technology (an incomplete list is reported in table 1). In this specific exercise it is important to specify how parameters change depending on RD&D funds, in particular the 'learning by searching' and 'learning by doing' ratios.

Other experts, or citizen panels, or focus groups, or awareness scenario workshops, or policy makers, will assign, prioritize and quantify that the energy system has to reach in the long term. According to the different targets/policy goals, the dynamic equilibrium global market of technologies (quantities) as well as the value of supplied energy services (price), calculated with models, provides quantitative elements for ranking.

Then these quantitative elements have to be combined with less quantitative social, political, administrative, etc. elements…

Arnulf Grubler, International Institute for Applied Systems Analysis
March 28, 5:51 am

I have followed your exchanges with interest, and offer below my two cents as well.

Basically I strongly agree with Lee [Schipper] and Bill [Moomaw] on the importance of energy efficiency as target for public sector R&D.

Three reasons:

a) research shows that energy efficiency is significantly underrepresented in both public and private energy R&D portfolios worldwide which all have a significant supply-side technology bias.

Just two illustrative numbers: since 1974 (1974-2008) OECD countries (represented in the IEA) have spent a total of 38 billion $(in PPP terms) in public energy R&D on energy efficiency, but 41 billion alone on fusion power, not to mention the 184 billion on nuclear fission (total public R&D budget: 417 billion $, i.e. efficiency is a meager 9%). This is in stark contrast to both history and future scenarios where energy efficiency (the decoupling of energy demand from GDP growth) is invariable the single most important option (and not any particular energy supply technology silver bullet). A brief paper illustrating these points is attached (which reports on a global analysis; I agree with Chris [Green] that national R&D priorities cannot be addressed without also looking at the global "optional" technology demand picture).

b) energy efficiency is also the technology (group) which yields the greatest multiple benefits. Lower demand (growth) improves not only the leverage effect of low- and zero-carbon supply options, and thus a double dividend for GHG emission reductions, but also has direct benefits for traditional air pollutants (human health), and energy security (lessened import needs and greater leverage effect of domestic energy production).

c) energy efficiency R&D projects also tend to be "granular" (smaller project scale in terms of $ needed) and thus offer significantly lower innovation risks (= failure rate times consequence {i.e. $ loss}) compared to "giga"-scale, multi-billion $ energy supply R&D projects (just think about ITER or FutureGen) that quickly can turn into innovation "lemons".

Lastly, as shown by the review of Fri (summarizing the NRC 2001 study), energy efficiency R&D projects have been the most successful in past DOE R&D projects, both in terms of success as well as social rates of return.

As a ballpark number: if we were to keep all supply side technology R&D as is currently, energy efficiency related energy R&D should be increased by at least a factor 5. A similar statement could also be made for basic (non targeted to any specific individual energy technology) energy R&D.

Fri, R.W.
The Role of Knowledge: Technological Innovation in the Energy System
(2003) Energy Journal, 24 (4), pp. 51-74.

NRC, 2001: http://www.nap.edu/catalog.php?record_id=10165

Lee Schipper, Stanford University
March 28, 10:01 am

Arnulf [Grubler] jarred me into thinking about all the trouble I got in during the Reagan years for advocating research. Yes, I wrote an Op Ed in the LA Times in 1982 arguing why we needed home and building system energy research. The Argument is simple. No home builder, real estate speculator, or other actor has any incentive to a) see what happens when components are put together in a system b) see how how theses systems use energy when real people are living or working in them and 3) how much fuel or electricity any particular technology or energy management strategy saves compared to no strategy. Again the "Twin Rivers" and "Hood River" projects of the 1970s and 1980s respectively scored very high in this respect, but our work has tailed off. Well the Reagan people didn't like this approach, and I'm not sure the Tea Party would today, yet in both cases one has to recognize the world we live in and try to get the most overall wellfare (not just knowledge) from public investments in R and D where there is no private incentive, particularly if the results cannot be "owned".

For example, at Twin Rivers, [Robert] Socolow and his team discovered "attic bypass" -- what seems trivial that a few square feet of poorly placed insulation or a thermal bridge might offset a huge share of the savings from adding attic insulation. Who can 'own' that system result? Given the small scale of home and even commercial buildings compared with large industries, it is hard for any home or building owner or manager to do much to understand how to save energy. With the proliferation of small electronics in buildings and homes we know less and less of how we use primary energy. Given that the household and commercial building surveys are only every five or so years now, and the last household service (RECS) has not even had the $$ or inclination to publish a detailed breakdown of household appliance ownership and, by regression analysis, unit consumption, we're blundering around. Commercial and public buildings are similarly blundering, in part because people don't use the buildings the way we predict and because the various fuel and electricity saving measures don't add up the way we model them to. In both cases a lot of submetering and sensing, which is now dirt cheap, needs to be done to guide further R and D. NAS has looked into these deficiencies and we hope they point the way to untethering a bit of money to pay for keeping our eyes open. Our ARPA-E project here at the Precourt Energy Efficiency Center is looking at some aspects of how consumers use fuel and electricity in their homes. But we need much more information than we have as a nation, given the diversity of climates, lifestyles, family situations that affect home occupancy day and night, home locations, and socio-economic situations of families.

We have several huge knowledge gaps. In addition to a black hole around the household and commercial sectors, we have not done a survey of fuel use in cars since -- ready -- 1985, when the same Reagan administration took the fuel-use diaries out of the then household energy survey as too much "respondent burden". The last nationwide household travel survey only asked about 'yesterday travel', omitting by definition about a quarter of our travel miles that didn't occur yesterday because by definition people who were on longer trips were not likely to be home "yesterday" when the surveyor called. We stopped surveying truck uses (including fuel) in 2002. We have no clue about how much fuel is used to haul a ton of a given kind of freight a mile, only some sense of aggregates for the major freight modes.

With cries for electrification of our auto fleet (cries I do not necessarily echo) we cannot make sensible predictions of who will drive what kind of car where and when it will be charged, or, in the case of a plug-in hybrid, whether it will be charged at all. We don't know how consumers will react to paying time of day charges for charging their batteries, not to mention whether they will pay carbon and oil taxes to guide their choices. Here there is a great need now for this kind of research. Toyota and other auto companies are doing some of it, but in my view too little now that the Leaf, Volt, and other key plug-in vehicles are launched or set to launch.

None of this is really "energy technology R & D", yet it all has profound impacts on energy demand and our energy future. And while Europe does a much better job than we at these measurement issues, almost nothing in the developing world is taking place. One result is clear from my 40 years—anyone in the U.S. can claim almost anything about energy use, "rebound effects" etc because our picture of ourselves and how we use energy is so blurred. Imagine if I went the doctor for a diagnoses and took last year's urin sample, borrowed Rob Socolow's blood pressure and Arnulf [Grubler's] blood count and asked the doctor "what is wrong"? That is about the state of what the U.S. knows about how its people and companies use energy.

Vaclav Smil, University of Manitoba
March 29, 7:25 am

How about four simple principles:

1/ NOTHING for nuclear, it has already received 96% of all federal energy funding since 1948.

2/ NOTHING for any biofuels that use any arable land.

3/ A VERY LARGE chunk for diffusing what we already know, most importantly how to build ONLY new energy-efficient structures (they stay for decades) and how we enact necessary building codes.

4/ ANOTHER LARGE CHUNK for modernizing and extending the grid: compared to Europe the country has no inter-regional interconnections and the grid looks quasi-medieval.

Nate Lewis, California Institute of Technology
April 7, 2:56 pm

DOE needs a portfolio of time horizons and risk profiles in order to maximize its chances of success. There is no one factor or metric that can be applied to all situations. Today's cost per unit of energy will not necessarily be a guide for next year's cost per unit of energy. Next, thermodynamic potential does not necessarily translate into economic potential because entropy plays a huge role as well as the first law of thermodynamics. What DOE should do is "think backwards" they should decide what the credible options are for an energy system that is near zero in something like year 2050. They are actually not very many such portraits. This has just been done in fact in a report entitled California Energy Future whose primary author was Jane Long and she might well share it with you before it is absolutely released for public consumption. Some of the portraits use existing technologies with cost and technology advances assumed to bridge key gaps; others assume the technology will be developed that bridge key gaps. In essence we need a technology strategy that follows the "business strategy" if your business is to have a near zero energy system or "go out of business" then you first make a map of what those systems look like and decide the key gaps that must be crossed in order to enable those portraits to become reality. Of course not all gaps will need to be crossed and there are many possible routes to success. The rule of R&D is then to buy one optionality when integrated over all the possible portraits maximizes the chance of having a successful outcome be reached. Also, when it is perceived that the value of the marginal dollar is equal across all possible investments then one is optimally investing in a diverse portfolio of risks across the technology supply value chain. This is how I see R&D as well as deployment being doled out an optimal way, also understanding that there are lots of surprises to be had and one needs to keep your options open for the optimal chance of success.

Max Henrion, Lumina Decision Systems, Inc.
April 14, 11:59 am

Focus on high-risk high-payoff projects: DOE should support high-risk early-stage projects, as ARPA-E is already doing, but with expanded funding. It should also support projects with high initial costs and payback periods too long for commercial investors—such as, CCS, nuclear, and enhanced geothermal. For technologies with moderate risks and potential returns in the not-too-distant future, the private sector should already be making appropriate investments, and usually is. There seems little reason for DOE to be funding RD&D in relatively mature technologies already widely commercialized (such as wind turbines).

Attend to minority opinions: We need to be looking for black swans — or rather "Gold Swans"—technologies that may have only a small probability of technical success, but with a potential huge impact. Standard government review processes tend to pay too much attention conventional expert opinion which tends to discount the potential of truly unexpected and disruptive technologies. According to Vinod Khosla, most venture capitalists share this tendency, which he aims to avoid. To find early-stage gold swans, it is a good idea to attend carefully to the most enthusiastic evaluations, if they are based on sound science, rather than averaging over experts.

Be explicit about uncertainties: Some have argued that the degree of uncertainty about outcomes of R&D makes it impractical to do quantitative comparisons among technology. On the contrary, the uncertainty makes it even more important to do so, and to be explicit about the uncertainties. Explicit risk analysis is critical if you are to appropriately evaluate and compare competing high-risk projects. A useful approach (suggested by the National Academies study, cited by Jay Apt) is to use expert elicitation to estimate the uncertainty about future cost-performance of each technology expressed as probability distributions over key metrics (such as $/KW or $/Kwh) conditional on levels of R&D funding. Yes, it's challenging to do well. But, in fact, DOE's Office of Energy Efficiency and Renewable Energy (EERE) has already made a good first cut, using expert panels to assess probability distributions on future cost and performance on 40 technologies. (Full disclosure: I assisted EERE in developing their elicitation protocol.)

Evaluate the combined effects of multiple technologies on the energy economy: The benefits of a technology ultimately depend on its market adoption — how fast it walks down the learning curves and so how well it competes against fossil sources as well as other low-carbon technologies. For example, the benefits of cheaper biofuels and batteries and plug-in vehicles depend on how they compete with each other, the price of oil and electricity, as well as future public policy to internalize carbon costs or achieve energy security objectives. A dynamic stochastic computer model can help us explore and understand these complex interactions, identify a variety of plausible scenarios, and prevent us fixating on a single "expected" future. EERE has supported NREL and six national labs to create such a model (SEDS or the Stochastic Energy Deployment System) designed to evaluate energy R&D portfolios. (Full disclosure again: I assisted NREL in developing SEDS, which uses Lumina's Analytica software.)

Consider U.S.-centric metrics and green jobs: DOE analysts tends to focus on three metrics for comparing energy technologies: Levelized cost of energy, GHG emissions, and energy security, quantified as reduction in oil and gas imports. These are, of course, important. But if the USA cared only for these metrics, it might save money by letting other countries do the expensive R&D for green technologies, and the even more expensive early-stage deployment as the technologies walk down the cost-learning curve (as, for example, Germany did for photovoltaics). Then the USA can simply buy the products from foreign manufacturers once they become more affordable. The USA already appears to be moving along this path, allowing other countries, notably China, to win dominant market shares for manufacturing wind turbines and photovoltaics, as Thomas Friedman likes to remind us.

But, given that the U.S. DOE is indeed serious about stimulating domestic clean-tech industries (as demonstrated by its funding and loan guarantees for U.S. manufacturers) it should also emphasize a fourth metric for evaluating its RD&D spending: The potential of the technical success of each R&D program to build a successful domestic industry and green jobs. While this objective is even harder to estimate than the first three metrics, it may get inadequate attention if it is not included explicitly along with the other three metrics. Given the very modest RD&D funds available to DOE ($4.3 billion, only 2% of the over $200 billion World clean-tech expenditures in 2010, according to the recent Pugh Foundation report), it would be wise to set a careful strategic focus on those technologies most likely to result in a domestic industry, and perhaps cede some technologies and markets if the USA is not willing to invest enough to cover the full range (more on this below).

Phase 2

Near Zero, (Steven Davis, Carnegie Institution for Science)
April 1, 4:40 pm

Dear Energy-system Experts,

Thank you for the thoughtful comments on the factors DOE should consider in allocating RDD&D funds. For the next phase of this discussion, we would like you to imagine you have the power to allocate the $4.3B federal investment in RD&D as you see fit.

Please allocate funds across the categories below as percentages, assuming you can also direct allocation within each category. (The categories below are taken from the DOE Framing Document: bit.ly/e2BiZP).

1. Transport
____% 1.1 Increase Vehicle Efficiency
____% 1.2 Progressive Electrification of the Vehicle Fleet
____% 1.3 Alternative Fuels
____% 1.4 ______________

2. Stationary
____% 2.1 Building and Industrial Efficiency
____% 2.2 Modernize the Grid
2.3 Adoption and Deployment of Clean Energy Supply
____% 2.3.1 Nuclear
____% 2.3.2 Wind
____% 2.3.3 Concentrating Solar Power
____% 2.3.4 Solar Photovoltaic
____% 2.3.5 Carbon Capture & Storage
____% 2.3.6 ______________
____% 2.4 ______________

More important than your actual allocation are the factors that you used and how you applied them in your allocation. Please explain the factors you have considered and applied in making your allocation. For reference, a transcript of responses we received including the factors suggested during the first phase are attached.

If you would like to allocate these resources more narrowly within categories, feel free to tell us that more specific allocation. If you think this taxonomy is not helpful or needs amendment, feel free to provide us with an alternate taxonomy. Again, understanding your reasoning will be more helpful than your specific suggestions.

Because we would like to get independent responses (and not overload people's inboxes), please reply directly to doe_priorities@nearzero.org (the sender of this email).

We look forward to your responses,

Steve Davis sjdavis@carnegie.stanford.edu
David Keith keith@ucalgary.ca
Ken Caldeira kcaldeira@carnegie.stanford.edu
Karen Fries kfries@nearzero.org
Brian Arbogast barbogast@nearzero.org

Jabe Blumenthal jblumenthal@nearzero.org

Near Zero will submit responses, with attributions, to DOE by 15 April 2011. It will become part of the public record and be posted on the web.

If you have further questions, please contact us; doe_priorities@nearzero.org forwards to the signers of this email. All comments will be considered part of the discussion to be published unless you explicitly ask for them to remain private. If you would like to be removed from the email discussion, please send mail (can be blank) to optout@nearzero.org.

Vaclav Smil, University of Manitoba
April 1, 5:12 pm

Increase Vehicle Efficiency “nothing else can take you from 23 mpg to 70 mpg that fast”
Progressive Electrification of the Vehicle Fleet “adjunct to the above”
Alternative Fuels “relatively a minor concern providing you succeed with the two above”
Building and Industrial Efficiency “longest-lasting (decades) returns”
Modernize the Grid “with D+ grade as it is now it is about time to make it half decent”
Nuclear “Got more than $ 100 billion already since the 1940s”
Wind “no fundamental breakthrough can be made”
Concentrating Solar Power “a great adjunct to natural gas”
Solar Photovoltaic “ultimately the best way to go in conjunction with all of the above”
Carbon Capture & Storage “a fundamentally wrong way to approach the problem”

Christopher Green, McGill University
April 2, 11:03 am and April 3, 8:19 am

1. For what they are worth here are my allocations (below). Frankly I am not comfortable with this sort of exercise. I set out my views in earlier e-mails, where I tried to indicate why I think establishing “criteria” requires context, and from the resposnes to your call, there appears little agreement on this.

Instead of reflecting “generic” criteria, my allocation reflects where I think more energy R&D might do the most good. Utility scale storage for solar and wind is a first priority. However, it gets a lower % (20%) than grid modernization (25%) because it seems to me the latter should include substantial infrastructure costs (actual grid build), and that will require more funding than the basic R&D needed for breakthroughs in utility-scale storage. with regard to other allocations, since we are going to need some help from nuclear and CCS, I have allocated 15% to each. In both cases these are technologies where we should be working with other countries (including China, Korea and India) and sharing some of the R&D costs with them.

Incidentally, I liked some of the points made by Dale Simbeck. I had not seen/received his views until today when you circulated his e-mail alone with the others. It is his e-mail that led me to give 20% to building efficiency. Dale refers to an attachment that he sent along with his e-mail to you. Would you be able to pass along the attachment to me?

2. I have a further thought that I had intended to include when I made my allocations. It seems to me that it makes a difference whether one is allocating an amount (here it is $4.3 billion) on a one shot basis, or whether there is assurance that there will be continued funding of at least the same amount each year over many years.

It seems to me that the payoff from allocations to major long-term R&D initiatives may be very small if there is no assurance of continued funding. The result of the present stop-and-go approach to funding, that seems inherent in the Congressional process, undermines long-term initiatives and may bias spending to projects which only need short term funding and with near-term payoffs, if any.

As you know I believe that what is needed is a science-driven (including testing and demonstration) of a long-term energy technology revolution. Along with my colleague Isabel Galiana, we have proposed a $5.00 /t$CO_2$ tax (fee). For the U.S. alone that would raise $25-30 billion per year. We have proposed that the funds be placed in a dedicated trust fund along the lines of the U.S. Interstate Highway trust fund. This would provide not only a consisitent source of funding, but with at least has some arms length from the Congressional process.

If $5.00/t$CO_2$ is too much to expect in the current political climate, then I would note that a $1.00/t$CO_2$ fee would provide a consistent $5-6 billion/yr. All that would require is ~1 cent/gallon gasoline; ~ 5 cents per 1000 cubic ft natural gas; and a little less than $3.00/tonne of coal at mine mouth.

It seems to me that even more important than getting DOE allocations right is getting some year-in year-out assured funding for energy R&D, testing, demonstartion. Incidentally, adding another 1 cent/tonne fee to could be used for a major upgrading of the electrical grid. And as to politics, I think that getting bi-partisan support for fully funded expenditures on something every one benefits from (the energy system), might be possible as Congress begins to look at entitlement, other expenditure, and tax reform as it takes up the deficit-debt problem.

Dale Simbeck, SFA Pacific, Inc.
April 2, 10:21 am

1. The best Gov. funded R&D ideas end up with researchers that leave the safety of “white collar welfare” (simply telling the funder whatever they want to hear) to start their own high-risk energy or environmental technology start-up company.
2. Our current regulated electric power system does not spend enough on effective R&D and commercial development of new, improved and innovate energy and environmental technologies. In fact, [public utility companies] encourage this. The best example of how our [natural gas] industry was just like our current electric power industry 30 years ago.

Steven Hamburg, Environmental Defense Fund
April 3, 9:51 am

My funding priorities reflect a few assumptions:

3. inefficient energy use provides the largest potential to reduce fossil fuel demand and ghg emissions
4. we do not know how to integrate new technology into broad use quickly (we do not have the systems to keep the trades current with the latest technology so implementation lags proven technology by decades)
5. we have not begun to figure out how to mange the grid optimally (shed load quickly, base load represents the bulk of demand, feed back to users to reinforce Efficient use)
6. we need to accelerate the integration of renewable energy sources into the energy system by figuring out where it does and does not make sense.

Hal Harvey, ClimateWorks
April 5, 9:01 pm

Transportation:

1. Transportation System Optimization

a. Background: In the United States, there is little money for construction of new roads, railways, or airports, yet we have an expanding population and a growing economy. These trends portend serious congestion problems and episodic system failures—unless the current system is significantly optimized.

b. System optimization has several dimensions—and several important obstacles, both organizational and technical.

i. Price use of existing infrastructure. Considerable academic research and operational experience argues that zero is the wrong price for road use, and by setting the price at zero, as we do almost everywhere, we get uneconomic overuse and very costly congestion. New technologies can offer congestion pricing with low capital cost. The revenues from congestion pricing can be used to support alternative transportation modes. The DOE, in conjunction with the DOT, could consider the economics of congestion pricing in several cities, analyze the technologies, and suggest possible strategies forward. Ideally the DOE and DOT could offer a "Race to the Top" style reward for a few cities who get in front.

ii. Optimize complex transit-sheds. Most U.S. metropolitan areas are served by between several and a couple dozen transit agencies. These systems are not optimized together—in routing, dispatch, maintenance, capital investment, or fare collection. This result of this is, predictably, slower and less frequent service and higher costs than necessary. The (DOE and DOT?) should develop system optimization software, and use it in one or two regions, to rethink and coordinate transit agency decisions.

iii. Logistics have vast potential for optimization. Some fleets are well along on this front—per UPS or Fedex. But most urban fleets do not have serious optimization. Developing intuitive, public domain software for smaller fleets, and testing it in several markets, could have a large impact at a small cost.

2. Neglected Vehicle Technologies and Strategies

a. Most auto and truck innovation has focused on drive trains—with great advances in engines, transmissions, hybrid systems and electric motive force. A complementary focus on vehicle mass is needed. Lightweighting, using advanced materials, can drastically cut energy use without compromising safety. Advanced materials (e.g. new metal alloys, fiberglass, advanced plastics, and carbon fiber) and advanced engineering (e.g. finite element safety cells, crush materials and crush space) are the keys to demassing autos without compromising safety. Lightweighting has compounding virtue: A lighter frame allows for a smaller, lighter engine; a smaller engine and lighter frame allow for smaller brakes and tires; these in turn allow the manufacturer to demass the suspension. And so on. Lightweighting needs research—in materials, in manufacturability, in strategies to reduce costs, in painting, and more.

b. As vehicles become more complex (greater electronic control of engines, hybrid drive trains that can dispatch gas or electric motors, batteries that can be sized for power, or energy, and so on), the potential benefits of optimization grow enormously. The auto industry has relatively little expertise in this realm. Developing some tools to optimize across these dozen or so variables could reap large benefits.

I am skeptical about Alt Fuels, and feel that electrification is not a panacea, but these need investment regardless, and I would hope to be proved wrong on both counts.

Buildings and Industry have NO ONE in charge of system optimization. This is where the big savings will be found.

Nuclear should be bifurcated between (a) managing existing, including dry cask storage, decommissioning, ideally funded out of other parts of DOE, and (b) serious exploration of modular, smarter future technologies. [In allocation, the respondent noted: Focus on 4th Gen, modular. Make sure rest of DOE nuclear budget includes serious focus on dry cask storage].

System optimization gets shoved out of stovepipe methodology….

Lee Schipper, Stanford University
April 6, 6:01 pm

There are a number of issues where energy efficiency R&D and US policies interact that Americans have dared not discuss in this country for decades.

1. What are the areas of research that cannot be capture by private companies or by definition get into the public sphere so cannot be "owned"?

I wrote an op Ed in the LA Times in 1982 strongly criticizing the Reagan Administration for dropping so much research on homes and buildings, sectors where almost no private actor has any incentive (or financial reward) for pursuing systematic solutions that save energy throughout the building or home, because private companies either make building components or put buildings and homes together, but rarely both, and they do not pay for the energy used in the buildings or by the devices. Among these kinds of topics are monitoring of energy use in buildings in much greater detail and diversity than is done to day, and an increase in the frequency and detail of RECS and CEBCS surveys. WE cannot diagnose our energy efficiency problems with spotty, old data!

2. Why are energy efficiency research projects not pursued in housing, building, transport, industrial, agricultural min-

istries? They are in most cases NOT energy driven issues, rather issues that belong to their respective sectors. I wrote a whole book on Swedish housing and energy (Schipper,5 Meyers and Kelly, “Coming in from the Cold” Seven Lock press, 1985, still there on Amazon)) and showed that energy efficient housing had little to do with energy but a lot to do with housing. As a result most of the housing efficiency problems in Sweden (and it turns out the other Nordic countries, Germany, France) were placed in the sphere of the housing sector, NOT the energy sector. I have more recently written a half dozen papers on why transport energy is NOT an energy driven issue, but more properly seen as a transport issue.

3. Why does DOE spend so little on data, analysis, etc on energy use. Imagine going to the doctor with a fake blood count (EIA simulated fuel use, since we have not had a car fuel consumption survey since 1985), last year’s blood pressure and a neighbor’s urine sample and asking for a diagnosis. Well, the US sector surveys are so infrequent and now increasingly incomplete we cannot say how or how well we use energy with the kind of accuracy required to be able to spot important trends in efficiency. We are the only major industrialized country without a regular set of energy consumption accounts in manufacturing, and we have no automobile or vehicle use and fuel consumption surveys any more.

4. Where to we put “visionary” and “systems research”. I confess to having been laughed out of DOE for using the word “lifestyles” in 1988, after I did one of my best studies ever, while at Shell International, on lifestyles and energy use. The issue of course is that DOE does research on widgets and things, but no one really looks at and measures SYSTEMS, and very little focus is on people both as consumers and as energy-using commercial decision makers.

I briefed Holmes Hummel and staff in January on my transport work and the vision I noted above that energy/CO_2 in transport was mostly a transport problem. They were fascinated by the presentation judging by the discussion. One of the people present was in charge of what used to be an NREL proposed study of transport that was in turn going to be carried out at Stanford last year. The focus would be on a low carbon transport system in 2050, something I have been working on for a Japanese sponsor. Well, it morphed into a call for four or five papers on various transport topics, some related to land use and car use. I noted that several of these topics had been flshed out in “Growing Cooler”, “Moving Cooler” and “Growign Wealthier”, studies done by NGOs and academics for EPA, the Shell Foundation and others from 2007 to 2011. I asked the NREL contact whom I met about this and wondered why a really pathbreaking study could not be undertaken. His sincere response was that DOE’s mandate was not about transport systems and could not address issues like land use, transport planning etc. Yet many recognize that these issues hide a greater potential for saved energy than just CAFÉ standards and research into low carbon fuels alone. I was not pleased with this siloed approach.

I think a larger issue has compromised most of our work for the past three decades, mainly our fear of looking outside of the box (or beyond the “nine-dotted square” as some say). I observe that in my 17 years at LBNL, most of my funding (in $) was from EPA, foreign governments (all four Nordic countries pumped in nearly $500K in today’s dollars), oil and car companies (donations) etc. Very little came from DOE because the systems approach that I fostered didn’t fit into any program. Indeed I left LBNL on my sabbatical at the IEA, which I defined as 6/7 of 7 years away from office, for some of the best research in my life.

When time was up at the IEA, I retired from LBNL because I realized I would never be able to fund the kinds of projects that interested me (and from my own publication record, apparently interested many others, but not DOE).

I founded EMBARQ, the World Resources Institute Center for Sustainable Transport in 2002 with money from the Shell Foundation. By 2005 a bus rapid transit system we fostered in Mexico City was moving 250 000 people/day saving them 10 minutes of travel time each way and saving 40 000 tonnes of CO_2 a year as a transport system. This is the kind of work the research beyind which seems beyond DOE’s grasp.

I came back to the University of California and Stanford, but did not return to LBNL. To me, too much of the efficiency research DOE funds is too oriented around “things” and various favorite items of constituencies. Too little is about people and how they use energy, although the ARPA-E project at Stanford is a good but rare exception. If I compare with what I have seen funded in the Nordic countries I’m amazed. I worked on LBL-directed funds from all four countries and sat on the Swedish Transport Research Council for 4 years funding transport/environment projects so I know a little about the different approaches. The private sector did much of the “thing” research, while the public sector fostered the people and policy research. Consequently I had no interest in returning to a national Lab.

I think the reasons for my dissatisfaction lie in deeper trauma -- the US has never really come to grips with the fact that we do not have the capability to produce oil at even $200/bbl in amounts anywhere near the 21 million barrels per day we consumed before the crash. Since we don’[t know how to deal with pricing issues, so we have subsidized and incentivized energy production for the four decades I’ve been in this, again in stark contrast with how other, more civilized countries deal with this. Ethanol subsidies are but one of many of these examples, but all the various production “incentives” including those for renewables simply hide the real cost of energy from consumers and businesses

Consequently our efficiency research is very constrained to make cheap stuff cheaper, rather than figure out how to adjust our economy to more expensive energy that is inevitable. Here efficiency and efficiency research could play the game-changing role, so we could live well on more expensive (but hopefully cleaner) energy, but we’ve lost 40 years to working the other way.

I was in a meeting with Sec. Chu (with whom I shared my LBNL office in the 1970s) last June in Oxford (the WFEE). I sat where I could ask Steve the first question, and it was about pricing. He said “Pricing is off the table. We believe in incentives”. Well, even ignoring (small) rebound effects, incentives rarely get the majority of people and companies to move very far, both because we don’t have the money to bribe all of ourselves to buy different stuff, and because the incentives do not change how we behave and how we manage energy use, they only affect the THINGS we buy.

So where does that leave research after 40 years of being a kind of prisoner to our own hangups about cheap energy and denial about what we could produce, cleanly. As long as this is the overriding centerpiece of our energy policy, I see little coming from energy efficiency R and D. Rather than preparing us for the future, our R&D policy, by being constrained to a vision of cheap energy, is keeping us a prisoner of the past.

Thus to me the most important research question today is how to get America off of its “cheap energy” syndrome. This is not to make war on the “drill drill drill” syndrome but the two are related and have imprisoned our entire energy policy debate for the forty years I have spent in the field.

Arnulf Grubler, International Institute for Applied Systems Analysis
April 7, 11:52 am

Criteria used for R&D resource allocation:

Analysis of ensemble of global scenarios in which the contribution of different technologies to 3 interrelated overall energy/social objectivesare determined through extensive scenario sensitivity analyses.

Objectives include:

energy security, climate change mitigation, reduction of energy poverty and providing adequate energy services for economic development.

Scenario results are then combined with a stylized global model of multi-criteria optimization across these three objectives varying the degrees of fulfillment of individual and joint objective functions. Numerical values are (rounded) averages and should be considered as “stylized” model results from a global perspective that are deemed nonetheless characteristic for developing “guideposts” for U.S. policy also.

Bottom line:

>50% on enegry efficiency (as generic option most suitable for all 3 energy objectives - higher efficincy=less energy demand (growth) and thus less need for energy imports (security objective), lower emissions and higher impact from diffusion of low-carbon technologies (climate objective) and higher “bang for the buck” (more services/energy input) (energy poverty and devlopment objective)

~20% on basic research and novel concepts (new solar, CCS).

<30% on zero-carbon supply side options.

My percentage allocation is shown below (following the prescribed format, I however strongly disagree with).

Increase Vehicle Efficiency (higher R&D needs compared to buildings and industry as “tough” problem)

Progressive Electrification of the Vehicle Fleet (no basic R&D need for public sector, industry does already batteries)

Alternative Fuels (focus on 3rd and 4th generation biofuels and hydrogen)

Building and Industrial Efficiency (with focus on energy intensive industrial processes and cheap buildings retrofit efficiency measures)

Modernize the Grid (focus on low cost underground electricity cables and socially acceptable CO_2 transport infrastructure [shipping rather than piplelines])

Nuclear (focus on safety and disposal, NO new generation nuclear, 0% for fusion)
Wind (mature, only offshore upscaling R&D needed)
Concentrating Solar Power (focus on energy storage, water minimization, cost reductions)
Solar Photovoltaic (low cost "plastic" PVs)
Carbon Capture & Storage (focus on learning from many small "granular" CCS projects, NO large "upscaling" demonstration projects)

Nate Lewis, California Institute of Technology
April 7, 3:02 pm

I have basically given equal leanings to the big areas that I think are ripe for RD&D. Electrification of the vehicle fleet means both light-weighting vehicles and better batteries and energy systems which industry cannot now do because it is too risky. Alternative fuels in important not just for light duty vehicles but especially for aircrafts, ships, and heavy duty trucks that essentially cannot be electrified. There would seem to be no option other than to use carbon neutral fuels for this process.

Carbon capture and storage obviously needs work both in the research as well as demonstration, development, and deployment. I also added a category for renewable fuels and energy storage because that is enabling technology to compensate for intermittency, which is a key gap in our energy system. Those are 80% and I would divide the remaining 20% in a "pick them" fashion. These are the things needed to get to zero and to get to scale and are the missing gaps in our ability to do so now. Which is why I picked them in about equal weight. We don't have to get all of them done, but we have to get at least some of them done to get to near zero and thus in the portfolio approach by optionality equally weighting them seems appropriate.

William Moomaw, Tufts University
April 8, 9:28 am

I agree with Hal Harvey that we need to both improve efficiency and move to low carbon technologies. The scope of renewable contributions is greatly enhanced by requiring lower end use energy requirements due to the smaller power densities of some renewables.

Increase Vehicle Efficiency This is essential for near term (5-10 years) reductions in oil consumption
Progressive Electrification of the Vehicle Fleet This is the most viable option for a transformed low carbon transport system inn the long term (10-20 yrs)
Alternative Fuels Biofuels are very problematical in terms of net energy saved and the high fossil fuel input. Effort should be on algae, perennial crops and must be conducted with proper carbon and energy accounting.
High speed rail This can make a very large difference in reducing air and car travel in an electrified way that reduces carbon emissions in next 20 years
Building and Industrial Efficiency Building efficiency can be improved dramatically within the next ten years, and working with industry to improve industrial efficiency can bring large gains in energy productivity within a decade
Modernize the Grid This is critical for utilizing renewable energy technologies and for having an energy efficient system for providing energy services such as transportation, industrial and building functions. This should include storage and management practices.
Nuclear After 50 years nuclear research should focus on safety, and distant technologies such as gas cooled and more inherently safe designs
Wind Large potential for making a difference soon. Need to find ways to lower costs and to deal with variability
Concentrating Solar Power Means for cooing with little water, and for lowering costs
Solar Photovoltaic Need to work on alternative technologies to silicon based technology to bring down costs with thin film, and new materials. Balance of systems cost savings.
Carbon Capture & Storage This is very long term, and we need to have demonstration technology to find the real problems.

Geothermal Very promising, but underfunded. Can be important in specific locations and should be addressed.

Jane Long, Lawrence Livermore National Lab
April 8, 3:24 pm

My comments are based on a study of California's Energy Future by the California Council on Science and Technology. The summary report should be released in a few weeks and can be made available to Steve Koonin. My comments are brief and I cannot go into more detail right now because I am traveling, but the report will support many of these conclusions. Also, I am not going to comment on percentages because I really don't know exactly what to say at this point.

First, I am not sure why the transport and stationary are a good way to break down the program. I would say that there are 4 key strategies in reducing carbon from the energy system and these strategies should inform research priorities:

1. Increase efficiency in buildings , industry and transportation
2. Electrify transportation and heat
3. De-carboninze electricity
4. De-carbonize the fuel supply

In each category, there are existing technologies and implementation is more related to policy and may have other barriers such as cost. There are other technologies that need demonstration, and some that need much more development. Finally, breakthrough technologies in certain areas could make a huge difference. I would say that the strategic elements above also, serendipitously have increasingly more technology needs from 1 to 4. That is we largely know how to do the efficiency gains and electrification we need, we could do some research to reduce the costs, while decarbonizing electricity will be hard to do without either CCS, passive safety nuclear or technology to allow intermittent renewable to play a larger role without creating emissions by firming the power with natural gas or sacrificing reliability. Decarbonizing the fuel supply will be even harder as the methods we have in the pipeline today are largely related to biomass which will likely be inadequate in supply because of food issues, or they are really expensive or they require very complex unproven arrangements.

My educated guess—based on work we have done for California -- is that in each of these four categories, technology we know about and is at least in demonstration could solve about half the problem—that is get us at least half way to eliminating CO_2 emissions, maybe more. Further, the last half of the problem will take the most work and technology development.

First, DOE should aim for technology needed for the first half of the problem, and then look to the longer term needs.

The Office of Science at DOE should be in the business of developing options and should do those things that venture money will not do. For example, there is a lot of venture money in biofuels and solar energy with perhaps some exceptions for basic science to underlie these technologies.

So, these would be my priorities, with 1 and 2 largely affecting the first ½ of emission cuts and #3 will be required in the long run to finish the job.

Make de-carbonized electricity work:

a. Safe nuclear power
b. Get CCS to work
c. Get energy storage and grid management working.

Obstacles to electrification: e.g., Batteries for electric cars.

Advanced fuels that are not based on biomass and could be used as true offsets (ie CO_2 sequestration not related to energy production). The venture world is working hard on biofuels from biomass. The utility of biofuels for transportation will largely depend on the availability of biomass and secondly on the technology and the use of biomass is going to end up being a policy problem. So biofuels are being worked very hard by venture money and the implementation problem will be a policy problem. Instead, I would be sure to focus on what is a very large gap: technologies available for de-carbonized fuel that does not interfere with food production—ie fuels that are not dependent on biomass.

Martin Hoffert, New York University
April 8, 4:57 pm

The DOE Framing Document gives a clear statement of objective of this RD&D:

"President Obama has articulated broad goals for reducing our dependence on oil, reducing pollution, and investing in RD&D of clean energy technologies in the United States to create jobs. These include: (1) Reduce energy-related greenhouse gas emissions by 17% by 2020 and 83% by 2050, from a 2005 baseline. (2) By 2035, 80% of America's electricity will come from clean energy sources. (3) Support deployment of 1 million electric vehicles (EVs) on the road by 2015."

From previous peer-reviewed published work we know that a near-zero phase out of fossil fuel CO_2 by midcentury requires 30-40 terawatts of installed carbon-neutral power generating capacity by midcentury or shortly thereafter worldwide for continued economic growth at present rates (Hoffert et al. '98; Hoffert et al. '02; Caldeira et al. '03). This would, according to our best climate change estimates, keep global warming < 2 degrees Celsius, above which some trained climatologists believe irreversible polar cap melting with eventual inundation of coastal zones and cities will occur, albeit that some ideologues in Congress think global warming a hoax. However, the Department of Energy serves the interests of the American people long-term and should base its RD&D policy on the best science letting the chips fall where they may. Even if the funding level of 4.3 $billion a year is insufficient to accomplish the President's goal stated above, as I believe it is, DOE should organize its energy research to accomplish that goal, while campaigning for greater funding. I believe Energy Secretary Steve Chu is doing that. My allocations, comments and reasoning (in bold type) below aim to best accomplish the President's objective goals through DOE's clean energy RD&D. To that end I suggest some new program starts and argume for a different emphasis in some existing programs relative to the DOE framing document:

1. Transport (Total = 100%)

15% 1.1 Increase Vehicle Efficiency: ultralight bodies and frames, composites, carbon nanotubes, power management, tires, roads, traffic & collision avoidance feedback

35% 1.2 Progressive Electrification of the Vehicle Fleet: battery manufacture & ecology, motors, material recycle, power controls, catalysts, advanced batteries (particularly very high energy density lithium-air batteries)

20% 1.3 Alternative Fuels: hydrocarbons synthesized from CO_2 for carbon-neutrality, algal biofuels & hydrogen for air and sea transport including cargo-hauling blimps & sail-augmented ships

30% 1.4 Transformative transportation tech (NEW PROGRAM): maglev, high-speed rail, smart cars & trucks, bike, motorbike, Segway and rolling roads integrated with rail commuting, computerizing transporation infrastriucture, wireless electric power and recharge of cars and trucks from roads.

2. Stationary (Total = 100%)

10% 2.1 Building and Industrial Efficiency: Much good efficiency R & D has been done by DOE, not enough implemented. Emphasis should be on getting Americans to experience how advanced insulation, selective coatings, new lighting technology, smart grids with time-variable electric rate structures, passive heating and cooling, and the rest will impact architectures of entire homes, office complexes, factories and communities: Imagine, for example, a street from the DOE Solar Decathlon -- many streets with other solar structures would be even better -- on display at Disney World where it would be experienced by millions of visitors. Time to re-imagine from a 21st Century perspective Disney's half-century old "Futureland" of the Jetsons still on display. In DOE's new version, visitors will experience how a renewably-powered future can positively impact their and their children's lives. For industry, the low-hanging fruit may simply be redesigned "Victorian" piping and pumps to minimize losses. This might also be displayed in theme park setting. Time to stop whining "market failure" and do actual marketing. We know, for example, that the growth of modern suburbs was greatly stimulated by the General Motors 1939 World's Fair exhibit "Democracity," which showed a future in which commuters driving GM cars living in suburban homes drive to and from hub cities to work on highways through "greenbelts." People lined up for five hours to get in. Pent-up demand for this vision by the end of the war led to the nationwide Levittown-like building boom and present-day suburban sprawl. Be careful what you wish for. So let's wish this time around for the right thing.

10% 2.2 Modernize the Grid: DOE should focus on utility-scale storage, the main hurdle to major market penetration of intermittent & decentralized terrestrial renewables, after the cost of the energy converters themselves. We have nothing commercially on the shelf, though compressed air energy storage, flow batteries and flywheels are potential options -- pumped hydro not being feasible for most of the U.S.. You can't even get reliable test data on the round-trip efficiencies of these. I'd leave grid power management including whether and where to switch from AC to high voltage DC for long distance power transmission, distributed generation systems, and perhaps smart grids to EPRI, who are closer to the utility industry, and focus DOE on transformative breakthroughs like whether we can implement something like Buckminster Fuller's continental and global transmission grid, perhaps enabled by high-temperature superconductors

2.3 Adoption and Deployment of Clean Energy Supply

15% 2.3.1 Nuclear: The major problems of operational safety, waste disposal and limited availability of U-235 fuel to meet a 10 terawatt target by midcentury and beyond could in principle be addressed by (1) modular helium gas-cooled reactors (whose fuel pellets, not being water-cooled or water pumped, could not intrinsically suffer a loss-of-coolant accident like TMI or Fukushima); (ii) integral fast reactors (which among other things internally transmute long-lived actinides to less radiotoxic species) and (iii) thorium breeders (which burn U-233 bred from thorium -- in principle hundreds of times more abundant than the present reactor's U-235 whose identified resources and reserves have less energy than natural gas, and are hence likely to be depleted early on at a 10 terawatt burn rate). Small thorium underground reactors burning nuclear fuel that also addresses operational safety and waste disposal was proposed by the late Edward Teller and colleagues including the LLNL Lab Director are unfunded by DOE; though Bill Gates supports a small program in a related technology. DOE should be supporting RD&D in these technologies since they address real problems that must be faced to meet the President's goal which present fission program do not.

10% 2.3.2 Wind: The main problem of wind, like solar, is integration into the utility grid structure underscoring the issue of storage; although transmission is also an issue as the best winds apart from offshore are in the Great Plains. Wind turbines themselves are pretty close to their best efficiency.

10% 2.3.3 Concentrating Solar Power: This subsumes two sub-technologies: Concentrators employ one- or two-axis sun tracking to focus reflected high-intensity sunlight at a focal point at which there are either (i) PV cells tolerant of high temperatures (e.g., GaAs) or (ii) tubes filled with a high temperature heat transfer fluid like liquid sodium conveyed to a heat engine to generate electricity. Priority should go to testing claims by advocates that the second approach, solar thermal, is more efficient than PV, and able to store significant energy in the bargain, as widely varying numbers are found in the literature.

15% 2.3.4 Solar Photovoltaic: The main issue is manufacturing cost, moving rapidly down the "learning by doing" curve, unless clearly more efficient or cheaper cents per kilowatt-hour photoactive layers can be found to the present crystalline silicon and thin film technologies. Again the limiting factor for the penetration of this technology at the mutiterawatt level is likely to be utility-scale storage.

10% 2.3.5 Carbon Capture & Storage: As with other carbon-neutral energy technologies capable in principle of mutiterawatt electric power generation the immediate need is for full-scale demonstration facilities with which to test various centralized CO_2 removal technologies from coal-burning or coal-gasifying power plants. Long-awaited, the FutureGen experimental facility has morphed from the initial idea of CO_2 removal from a coal-gasifier fueling thermodynamically efficient combined cycle power plants with both steam and gas turbines and CO_2 centrally collected to its present incarnation as an oxy-fueled conventional steam plant burning pulverized coal in pure oxygen generated cryogenically to expedite CO_2 removal. This latter technology might allow cost-effective retrofitting existing coal plants for oxy-combustion and carbon capture and storage (CCS) though the economics are very uncertain. CO_2 storage R & D can be pursued separately and indeed is an ongoing commercial venture for the Dakota gasification plant whose construction dates back to Jimmy Carter's synfuel program. In any case we need real numbers for these processes and government underwriting research risk before industry will commit to this technology.

10% 2.3.6 Space-Based Solar Power (NEW PROGRAM): It's outrageous that SBSP, which exploits the 24/7 availability of sunlight in geostationary orbit at 7 times surface intensity to collect sunlight and beam it's energy to the surface by laser or microwave -- invented in the U.S. by Peter Glaser in the late 60s and now being studied by Japan, China, Europe, Russia and India -- has no DOE home or funding in the U.S. a despite strong interest by some at NASA to test the beaming part from the International Space Station. DOE and ARPA-E managers have resisted even being briefed by experts on this technology which, despite fears of space weapons and prohibitive costs, is relatively safe in itsinfrared laser version an comparable for base load to terrestrial PV even today at present-day launch costs. Though space-based and ground-based PV are 5 to 10 times more expensive than conventional coal-generated electricity today SBSP could in principle power the entire world carbon-neutrally and is more near-term than fusion funded worldwide at 10 $billion for ITER. It is arguably the job of DOE to conduct innovative physically plausible research across a broad spectrum of alternate energies including this one to cut costs enough to achieve the President's energy goals.

3.0 Energy Systems Integration (NEW PROGRAM) Develop and apply a new discipline, analogous to military or aerospace systems integration, for innovative & transformative energy options to design, identify and resolve critical technology issues. Without such tools, we would likely not have successfully accomplished the goals of NASA programs like Apollo, the Space Shuttle, planetary exploration missions and International Space Station, as well as countless weapons programs. Energy systems we must develop to meet the President's goals are at least as complex, and pose comparable challenges of technical virtuosity, as prior U.S. space and military technology triumphs.

M. I. Hoffert et al., Energy implications of future stabilization of atmospheric CO_2 content. Nature 395, 881 (1998).

M. I. Hoffert et al., Advanced technology paths to global climate stability: Energy for a greenhouse planet. Science 298, 981 (2002).

K. Caldeira, A. K. Jain, M. I. Hoffert, Climate sensitivity uncertainty and the need for energy without CO_2 emission. Science 299, 2052 (2003).

Max Henrion, Lumina Decision Systems, Inc.
April 14, 11:59 am

$4.3 or $43 billion? DOE's current $4.3 billion annual spending on energy R&D, at only about 2% of the $200 billion global clean-tech spending, is unrealistic for a country that aspires to be a leader in many clean-tech markets. Bill Gates and others have proposed expanding U.S. energy RD&D to $15 billion or more. If the USA decides it truly cannot afford to expand its energy funding, it would be wise to carefully select just a few areas where it can still hope to create a competitive domestic industry on which to focus its resources, and consciously cede remaining technology manufacturing to other countries. Or if it plans to become a leader in a wide variety of green innovation and manufacturing, it should greatly expand its R&D investment, funded perhaps by a low carbon tax. It must also choose other policies to encourage early adoption of any low-carbon technologies it may produce.

In the illustrative allocations below across a wide range of technologies, I assume that the U.S. is indeed willing to expand its public sector energy R&D spending very substantially. Otherwise, it might be wiser to zero out some areas rather than spread limited funds too thinly.

Vehicle efficiency: There is a large potential for radically improved vehicle efficiency, including new internal combustion engine designs and lighter materials, as well as the more topical battery and fuel cell vehicles. Success in this area is, of course, essential for the U.S. to maintain a successful automobile industry.

Biofuels: While the commercialization of cellulosic ethanol and advanced biofuels has been disappointingly slow in recent years, there are a wide range of promising technologies and improved sources of biomass. Some continuing support from DOE to supplement the extensive private capital is worthwhile.

Buildings: We know that a large fraction of energy use is in buildings, and there is tremendous scope for large savings from improved efficiency, as well as green jobs. Improved building codes, creative financing incentives, and training for workers are key. However, there is also potential for dramatic technology improvements, not just in materials and equipment, but also for fast inexpensive retrofit methods essential to reduce energy use in existing housing stock. Judicious RD&D by DOE can continue to accelerate development in these areas.

Modernize the grid: This is important and there are a few areas requiring RD&D (other than energy storage), but the large expenses are for deployment and should be borne by power distribution companies because they are cost effective, so need for DOE funding is modest.

Energy storage: Efficient, cheap, large-scale energy storage is an essential complement for solar and wind if they are to become a large fraction of power generation. There are many promising, early-stage new technologies, and DOE funding should continue to accelerate progress. This is area is wide open for innovative technologies, with the potential for growing a substantial domestic industry.

Wind: Wind power is maturing and commercially viable, so there appears to be little need for public R&D funding.

CCS: Developing demonstration CCS plants is expensive, and has little hope of financial return until low-carbon policies are adopted. U.S. Government support is essential if the U.S. is to develop leadership in this area that is likely to be important for reducing World-wide carbon reductions, but it is only practical with a much larger RD&D budget.

Geothermal power has a chance (e.g. according to a recent MIT report) of being a "silver bullet" providing 10s or 100s of GW of consistent low-carbon base-load power at reasonable cost, an essential complement to solar and wind, and otherwise available only from nuclear power. There are large uncertainties about the extent of suitable geologies, the longevity of facilities, and possible association with earthquakes. Exploratory drillings and demonstration projects are expensive with a long payback period. So we won't discover its actual potential without extended public funding.

Improving design and evaluation of an R&D portfolio: This exercise makes clear, if it wasn't already, that it's hard to to design and evaluate RD&D portfolios. There are large uncertainties inherent in R&D outcomes and multiple metrics. The benefits occur in the long run and are contingent on public policies to price carbon and encourage low-carbon fuels, as well as the highly uncertain costs of oil and other fossil fuels. Figuring out the potential effects on the U.S. economy and jobs is still harder. Because of the complexities, our intuitions will be faulty. In such situations, exercizes such as this by Near Zero and others, along with appropriate quantitative tools to explore scenarios and evaluate our assumptions can be especially insightful. Given what is at stake, the decision process should be careful and transparent. Decision analysts sometimes suggest that it's appropriate to spend around 1.5% of the budget at stake on allocating the budget. I have rounded up to 2% to reflect the challenges in this process.

Illustrative allocation assuming a larger RD&D budget. These are just a starting point for discussion. Any allocation should be revised regularly in the light of careful analysis, new evidence, opportunities, successes, and failures.

GianCarlo Tosato, International Energy Agency Energy Technology Systems Analysis Program
April 15, 8:07 pm

As mentioned in my answer to question 1, an update technology systems analysis would be necessary in order to allocate RDD&D funds to demand and supply technologies based upon their contribution to achieve different levels of energy security, climate mitigation and economic competitiveness. What follows is a list of observations and priorities based upon my experience and other non USA focused analyses.

1. It could help to keep in mind (and write in the documents) that what we need is not a progress, but an energy revolution: an almost zero GHG emission energy system (your document talks about -83% reduction in 2050, other countries talk about 90-95%) means satisfying similar services for heating, cooling, lighting, passenger and goods movements, etc. with a completely different supply / transmission / transformation / distribution chain.
2. It seems to me difficult to achieve such a revolution using the same laboratories, research facilities and researchers that failed to innovate the energy system in the past 50 years. New expertises and points of view seem necessary.
3. The demand for innovation is growing in quantity (because globally the demand for energy services is increasing) and in scope, because changes have to encompass end use sectors and their science fields. Even more so because decoupling growing demands for energy services with limited primary energy resources starts from end use sectors (building, transportation, materials use in manufacturing, etc.). For instance the efficiency improvements achievable in the primary transformation sectors (refineries, electric and heating plants, coal processing, etc.) can be measured in percentage points (a few), while energy efficiency improvements in end use sectors can be measured in terms of factors: 2, 4, even 10 in the housing sectors. This could be pictorially accounted for by reversing the order of the boxes in figure 2 "Six Strategies" page 22 of the document "DOE-QTR_Framing.pdf" and scaling the 6 boxes to the contribution of the six sectors to the three policy goals: security, competitiveness, and climate.
4. In my opinion money spent in socio-economic research activities aiming to involve in the energy RDD&D effort the end-use sectors where energy is used could bring positive results. The research question is here: how could energy, with

its three vital goals of security, competitiveness, and climate, take the lead and convey forces operating in end use sectors such as transport, building, material cycles, etc. to the same policy goals?

5. Globally, but even more in the USA, the balance of power in the energy sector seems too much in the hands of suppliers. This is easy to verify by comparing the actual energy supplied to satisfy any kind of energy service with the much lower levels theoretically possible. So the second research question is how to develop a system where in decision making consumers have the same weight of producers, as suggested by all economic theories. Why so many consumers don't know how to use efficiently the energy they pay and save a lot of money without reducing the energy services they enjoy now?

6. The associated research question is why it is not yet clear that the economic growth activated by spending domestically in innovative and much more efficient technologies in any kind of end use sectors is much higher than spending in pumping oil & gas abroad or digging coal? Furthermore it gives an edge in international competitiveness. Eventually intellectual resources are far less limited than fossil resources!

7. I would allocate large amounts of RDD&D funds to the building sector where a factor 10 efficiency gain is achievable and similar but lower amounts to the vehicle efficiency sector, where important although lower efficiency improvements seem achievable. Part of this budget could be usefully used to make consumers aware of the advantages of using energy more efficiently and enjoy better energy services.

8. I would allocate important amount of funds to make a revolution in the way electricity is made available to consumers: the present centralised electric grid system is a century old, like Internal combustion engines. The only sector in real need of base as well as applied research seems electric storage.

9. Since solar PV seems still capable of 'learning by searching', as well as 'learning by doing' I would allocate some funds to solar PV R&D and a considerable support to the deployment of solar PV with carefully studied subsidies, to be reduced till the full competitiveness is achieved.

10. Some funds could go the CCS demonstration plants, as well as ocean technologies for electricity generation.

11. I would not spend a cent on the following areas:

1.2 electrification of the vehicle fleet, since it will happen by itself as soon as electric grids are smarter, distributed and with good storage capabilities, and vehicles more efficient

1.3 alternative fuels from biomass, because they destroy the food market

2.3.1 nuclear, because the original promise to be 'too cheap to meter' continues to be wrong, on the contrary it becomes more and more problematic, risky and unaffordable both economically and socially

2.3.2 wind, a technology which became competitive against the official research and will now increase its market share where the grid will be adequate

2.3.3 concentrating solar power, because the potential technological improvement seems low and the storage potential advantage will be reduced with improving electric grids.

Appendix II

Expert Allocations of DOE Budget

	Vaclav Smil	Chris Green	Steve Hamburg	Hal Harvey	Arnulf Grubler	Nate Lewis	William Moomaw	Martin Hoffert	Max Henrion	Dale Simbeck
1. Transport										
1.1 Increase Vehicle Efficiency	28%		15%	15%	30%		6%	8%	15%	15%
1.2 Progressive Electrification of the Vehicle Fleet	8%		10%	5%		20%	10%	18%	3%	5%
1.3 Alternative Fuels	4%			10%	5%	20%	2%	10%	12%	10%
1.4 "Utility Scale Storage"		20%		10%					8%	
1.5 "Optimizing fleets and transit, and lightweight trains/transit"										
1.6 "Understanding of mobility drivers and leverages for behavioral change and offsetting take-back..."					5%					
1.7 "High-speed rail"							3%			
1.8 "Transformative transportation tech"								15%		
1.9 "Public transportation, job and residents organization innovation"										10%
2. Stationary										
2.1 Building and Industrial Efficiency	24%	20%	20%	10%	25%		20%	5%	27%	15%
2.2 Modernize the Grid	18%	25%	20%	5%	5%		20%	5%	3%	10%
2.3 Adoption and Deployment of Clean Energy Supply										
2.3.1 Nuclear		15%		10%	5%		2%	8%	6%	10%
2.3.2 Wind	3%		5%	5%	1%		10%	5%		5%
2.3.3 Concentrating Solar Power	6%		5%	5%	2%		10%	5%	6%	5%
2.3.4 Solar Photovoltaic	9%		5%	10%	2%		10%	8%	6%	5%
2.3.5 Carbon Capture & Storage		15%	10%	5%	5%	20%	5%	5%	6%	10%
2.3.6 "Altogether new energy sources/technologies"		5%			5%					
2.3.7 Tidal			5%							
2.3.8 "Renewable Fuels & Energy Storage"						20%				
2.3.9 "Geothermal"							2%		6%	
2.3.10 "Space-based Solar Power"								5%		
2.4 Bioenergy			5%							
2.5 "System efficiency, system optimization"				10%						
2.6.1 "'hardware' research (materials, catalysts, etc.)"					5%					
2.6.2 "'software' research (social sciences, economics, etc. for improved understanding of energy demand."					5%					
3. "Pick them" approach						20%				
4. "Energy Systems Integration"								5%		
5. "Improved process and tools for evaluating portfolio and allocating RD&D funds"									2%	

Note: Italicized categories were suggested by expert respondents.

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