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The Insurance Value of Energy R&D

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Center for Global Security Research
Lawrence Livermore National Laboratory
P.O. Box 808 (L-189)
Livermore, California 94551
U.S.A.
Phone: (925) 422-6141
Fax: (925) 422-5252
Web site: http://cgsr.llnl.gov

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Robert N. Schock, Lawrence Livermore National Laboratory
William Fulkerson, Joint Institute for Energy and Environment at the University of Tennessee
Merwin L. Brown, National Renewable Energy Laboratory, U.S. Department of Energy, Chicago Operations Office
Robert L. San Martin, Midwest Research Institute
David L. Greene, Oak Ridge National Laboratory
Jae A. Edmonds, Pacific Northwest National Laboratory

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Contents

Abstract 1
Introduction 1
Four Energy Risks 1
Climate Change 1
Oil Price Shocks 4
Urban Air Pollution 7
Energy Disruptions 7
The Insurance Value of Energy R&D 8
The Spinoff Value of R&D 9
Bibliography 10

The Insurance Value of Energy R&D

Abstract

Energy technology research and development (R&D) can be viewed as insurance mitigating the potential effects of four key risks to the United States: (1) the costs of climate stabilization and the effects of climate change, (2) oil price shocks and the cost to the economy of cartel pricing, (3) urban air pollution and the resulting health costs to society, and (4) failures in the reliability of the energy infrastructure. But, how much should we be willing to pay for this insurance?

The value of energy R&D is estimated conservatively to be at least $17 billion per year. However, only about half of this total may be warranted because some R&D is applicable to more than one risk. Nevertheless, the total Department of Energy (DOE) investment in energy-technology R&D (about $1.6 billion in fiscal year 2000) seems easily justified by its insurance value alone. In fact, a larger investment might be justified, particularly in the areas related to climate change, oil price shocks, and urban air pollution. A larger investment may also be justified for the risk of disruptions in the energy infrastructure (e.g., power grid or gas pipelines because there was no systematic R&D program within DOE for this purpose until fiscal year 2001).

Introduction

This paper is a condensation of earlier work which examined the federal energy-technology R&D budget in fiscal year 1999 (Schock, et al., 1999). We have updated the data based on fiscal year 2000 figures and adjusted the conclusions where appropriate.

For each risk, we calculate the insurance "premium" value of R&D, *V*, as follows: $V_{R\&D} = CpE$, where *C* is the net present discounted cost of the loss, *p* is the probability of suffering the loss, and *E* is the effectiveness of R&D to reduce the cost should the loss actually be incurred. The effectiveness, *E*, is equal to the sum over all relevant technologies of the product of the probability of R&D success for any technology, after some number of years of R&D investment, times the potential of that technology for reducing the loss. This variable is admittedly subjective, and its value derives from our judgment in predicting R&D success. **Table 1** summarizes the estimated values in this equation for each of the four risks examined.

Four Energy Risks

Climate Change. Should it prove necessary, mitigating climate change will have a profound effect on the energy systems of the world, which, at present, are 75% dependent on fossil fuels. With regard to cost, Wigley, et al. (1996) estimated the cost of optimally timed mitigation strategies for stabilizing the atmosphere at various levels of CO_2 concentrations. They calculated that the discounted present-value cost to the global economy of stabilizing CO_2 concentration in the atmosphere at 550 ppm by volume* would be about $1 trillion, discounted at 5% per

*550 ppm (V) is about twice the estimated pre-industrial level of CO_2 in the atmosphere.

Table 1. The insurance value of energy R&D investments for various risks, using the equation V = CpE

(B = billion; FY = fiscal year)

Equation	Climate Change	Oil Price Shocks	Urban Air Pollution	Energy Disruptions
Potential cost to U.S. (C)	Varies with stabilization concentration (see Table 2)	~$400 B (R) plus the cost of paying cartel-inflated prices without a shock (see Table 4)	>$20 B/year	$26 B/year for electricity disruptions alone
(times)	x	x	x	x
Probability of incurring cost (p)	Varies (see Table 2)	0.5 cumulative total for next 10 years	1.0 (occurring now)	1.0 (occurring now)
(times)	x	x	x	x
Effectiveness of R&D to reduce cost (E)	Varies (see Table 2)	0.1 (conservative estimate) (see Table 4)	0.2 in 10 years (conservative estimate)	0.1 × (10 to 30%) = 1 to 3% in 10 years (conservative estimate)
(equals)	=	=	=	=
Insurance premium value of R&D (V)	$5–7 B/year	>$6 B/year for 10 years (discounted at 5%)	>$6 B/year (discounted at 5%)	$0.4 to 1.2 B/year (discounted at 5%)
DOE's FY2000 investment in R&D relevant to this risk (see Table 3)	$1.1 B/year	$0.6 B/year	$0.9 B/year	$0.3 B/year

year over the time period (centuries) necessary to stabilize the concentration. Edmonds, et al. (1997) estimated that this cost of stabilizing CO_2 concentration at 550 ppm by volume could be reduced to nearly zero if certain advanced technologies were developed and deployed beginning in the decade from 2015–2025.

In estimating the insurance value of R&D, we attempted to be conservative. We assumed that the chance that no stabilization action at all will be required was 35%; then, the remaining 65% was divided up among the ppm values for CO_2 by volume: <450 (5%), 550 (25%), 650 (20%), and 750 (15%). Then the cost of stabilization was calculated for two mitigation scenarios. Possible cost savings due to better technologies were estimated for each of these scenarios. Summing these cost savings over all four stabilization concentrations and both sets of scenarios (assuming both scenarios are equally likely) predicts the potential average value of R&D to be $0.83 trillion current dollars.

It was further assumed that the U.S. share of this R&D cost is equal to its fration of current global greenhouse gas emissions (~25%). The probability of R&D success is assumed to vary between 0.1 for 450 ppm and unity for >650 ppm (**Table 2**). This yielded a present value of the R&D investment of $0.11–0.14 trillion by using a discount rate of 5%. The corresponding annualized R&D expenditure range thus justified is from 0.05 × $110 billion to 0.05 × $140 billion, or $5.5–7 billion per year.

Table 2. Estimated value of energy-technology R&D for climate stabilization

(Costs are in trillions of U.S. dollars and discounted at 5%)

Target atmospheric stabilization concentrations, ppm (by volume)	**450**	**550**	**650**	**750**	**None**
1. Probability of needing to stabilize at each level	0.05	0.25	0.2	0.15	0.35
2. Cost to stabilize WRE[1] ($)	3.7	0.9	0.3	0.2	
3. Cost with R&D success ($)	0.4	~0	~0	~0	
4. Potential savings with R&D = 1 x (2–3) ($)	0.17	0.23	0.06	0.03	
5. Cost to stabilize WG1[2] ($)	4.5	2.4	1.3	0.5	
6. Cost with R&D success ($)	0.4	~0	~0	~0	
7. Potential savings with R&D = 1 x (5–6) ($)	0.21	0.6	0.26	0.07	
8. Average cost savings assuming WRE and WG1 are equally likely = (4+7)/2 ($)	0.19	0.41	0.16	0.05	
9. U.S. share (~25%) = 8 x 0.25 ($)	0.046	0.1	0.04	0.013	
10. Assumed probability of R&D success	0.1	0.5 to 0.8	1	1	
11. R&D value = 9 x 10 ($)	0.0046	0.05 to 0.08	0.04	0.013	
Sum of R&D values over all stabilization levels ($)	**0.11 to 0.14**				
Annualized R&D expenditures justified ($)	**0.0055 to 0.007**				
Annualized R&D expenditures justified for WRE only ($)	**0.0027 to 0.0036**				

[1] WRE after Wigley, et al. (1996).
[2] WG1 after IPCC (1995).

On this basis, the overall insurance value of this R&D is between $5 billion and $7 billion per year to the United States. It should be noted, however, that the current reference cases of Wigley, et al. (1996) and the Intergovernmental Panel on Climate Change (IPCC, 1995) assume a substantial and continuing improvement in technology. If current state-of-the-art technology had to be solely relied on, the cost of stabilization would have been approximately threefold higher. This autonomous improvement implies a considerable R&D benefit indicating that the insurance value of R&D is at least threefold greater, or $15–21 billion per year. To be conservative, we stay with the $5–7 billion per year value.

The fiscal year 1999 DOE energy technology R&D budget was analyzed for relevance to this climate change risk. The results of our analysis (**Table 3**) indicate that, in fiscal year 2000, DOE was spending ~$1.1 billion in mitigation-relevant research; an expenditure one-fifth to one-seventh as large as can be justified from the above argument. However, it should be noted that this investment often leverages a substantial matching contribution from the private sector. So, although the government investment is much less than is justified by the insurance value, the relevant total national effort is larger.

Oil Price Shocks. Monopolistic pricing of oil by OPEC has cost the U.S. economy an estimated $7 trillion (present value 1998 dollars) over the period 1970–1999 (Greene and Tishchishyna, 2000). The probability and timing of future oil price shocks cannot be predicted. Some believe the probability is very small, but since one is now occurring, the probability is certainly not zero. The cost of another oil supply curtailment of the size that occurred in 1973–1974 and in 1979–1981 could be very large. The cost to the U.S. economy of a large two-year curtailment of supply occurring in this decade has been estimated at >$400 billion in 1998 dollars (Greene, et al., 1998). Even if such a shock does not occur, cartel pricing may still result in very high costs to the U.S. economy.

These are relevant points for this analysis. First, even those who believe that oil supplies will be abundant in the long run expect short-term disruptions. For example, the U.S. Energy Information Administration's International Energy Outlook 1998 notes that short-term disruptions are likely. Second, the principal driving force enabling low oil prices and abundant supplies in the future is always technology. Thus, in a sense, these scenarios assume the success of R&D aimed at discovery, production, and conversion of liquid hydrocarbons and at increased efficiency of petroleum use or at finding economic substitute fuels. In the end, the argument is not over the value of R&D, but rather whether the public interest requires that the government take action to see that the necessary R&D is done.

The probability of an oil price shock is not constant with time, but rather increases as OPEC, and particularly core OPEC countries,* increase their market share. By the end of this decade, the core OPEC market share is projected to be at pre-1973–1974 oil embargo levels of ~40%. Also, as the recent tripling of oil prices proves, OPEC can effectively expand its market share by securing the cooperation of non-OPEC countries, such as Norway, Mexico, or Russia. As time goes on, the United States should be willing to pay more for insurance in the form of R&D investments. In addition, even if a price shock does not occur, oil-consuming economies may suffer economic losses if the oil cartel keeps

*Core members are Saudi Arabia, Iran, Venezuela, the United Arab Emirates, Kuwait, Iraq, and Libya.

Table 3. DOE's energy-technology R&D investments for fiscal year 2000 with estimates for relevance to the four risks of climate change, oil price shocks and oil cartel pricing, urban air pollution, and energy disruptions

Energy-technology R&D area	FY2000 Budget	Climate Change		Oil price shock		Urban air pollution		Energy disruptions	
		Relevance	Relevant Budget	Relevance	Relevant Budget	Relevance	Relevant Budget	Relevance	Relevant Budget
Fossil Energy	404[1]								
Coal and power systems	212								
Central systems	115	M[2]-H[3]	86	L[4]	23	H	115	L	23
Distributed systems-fuel cells and turbines	44	M-H	33	L-M	15	M	22	M	22
Sequestration R&D	9	H	9	[5]					
Fuels	20	L	4	H	20	M	10		
Advanced research	20	H	20	H	20	H	20	L	4
Petroleum production and processing	57	L	11	H	57	L	12		
Gas-production, processing, and infrastructure	32	H	32	H	32	M	16	M	16
Miscellaneous	28								
Program development and management	75								
Energy Efficiency	566								
Transportation	233	H	233	H	233	H	233		
Industry	175	H	175	M	87	H	175	M	87
Buildings	115	H	115	L	23	M	57	M	57
Policy and management	43								
Renewables	311								
Photovoltaics	66	H	66	L	13	H	66	L-M	23
Biofuels	71	H	71	H	71	M	35	L	14
Solar buildings	2	H	2	L		H	2	M	1
Solar thermal energy	15	H	15	L	3	H	15	L-M	5
Wind	32	H	32	L	6	H	32	L-M	11
Geothermal	24	H	24	L	5	M	12	L-M	8
Hydrogen	25	H	23	H	23	H	23	L-M	9
Hydropower	5	H	5	L	1	H	5	L-M	2
Electric energy systems and storage	38	M	19	L	8	L	8	H	38
International	4	H	4	H	4	H	4		
Policy and mgmt, NREL, and misc.	29								
Nuclear fission	52								
Nuclear-energy research initiative	22	H	22	L	4	H	22	L	4
Nuclear-energy plant optimization	5	H	5	L	1	H	5	L	1
Program direction and management	25								
Nuclear fusion	248	M	124						
Total energy-technology R&D	1581		1130		649		889		325
Office of Science (not including fusion or high-energy physics)	1341								
Basic energy science (BES)	779								
Computational and technology res. (CTR)	128								
Biological and environmental res. (BER)	434								
TOTAL energy R&D including BES, CTR, and BER	2922								

[1] All budget amounts in millions of actual dollars.
[2] M = medium relevance. Half of the budget applies to that risk.
[3] H = high relevance. The whole budget counts for that particular risk.
[4] L = low relevance. Only 20% of the budget applies to that risk.
[5] A blank space means that the R&D counts as zero.

Note: Not included under Nuclear Fission is any part of the $347 million for the Office of Civilian Radioactive Waste Management funded in part by a tax on utilities with nuclear power plants for the purpose of establishing a permanent repository for spent nuclear fuel. Also, no part of the $255 million for research by the Office of Nonproliferation and National Security is included. Also, not included is $100 million being spent on inertial fusion by the National Nuclear Security Administration. Some significant portion of the budget for the Office of Science is applicable as basic research support for the energy technologies, but the allocation is unknown.

R&D in a given area may be relevant to more than one risk, thus the sum budget amounts for the four risks may add up to more than the fiscal year 2000 budget totals.

prices above competitive market levels. This cost is also considered when estimating the insurance value of R&D, and this portion—which is longer term—seems more amenable to reduction by R&D than does the cost of the shock itself.

Greene (1996) estimated the cost savings to the U.S. economy if technologies were developed that could double both the short- and long-term world price elasticities of oil supply and demand from 1995 to 2005. These savings are enormous. If a protracted oil price shock were to occur in the latter part of the this decade, the present value of the savings to the U.S. economy is estimated to be ~$590 billion in 1999 dollars, assuming a 5% discount rate and the scenario analysis methods of Greene, et al. (1998).

Table 4 gives estimates of the potential cost savings for this risk as a function of the effectiveness of R&D success. Even if the effectiveness of success is as small as $E = 0.1$ (i.e., 10% of the hoped-for results are achieved), the annual willingness to pay or insurance value is $6 billion per year for 10 years. The probability of an oil price shock over the next 10 years is taken to be $p = 0.5$. It derives from the fact that, over the past 25 years, there have been four shocks including the most recent one. If these events are independent, the probability of a shock was $\sim p = 4/25 = 0.16$/year. Thus, the probability of a shock in 10 years is $p = 0.825$, so $p = 0.5$ would seem to be a low estimate for this time period. The value of insurance could be much higher if the probability of R&D success (its effectiveness) is $E = >0.1$ integrated over 10 years.

Table 4. Potential value of R&D for reducing the cost of oil cartel pricing and oil price shocks

(Billions of 1999 dollars)

Value of Doubling Price Elasticities of Oil Supply and Demand		Probability of R&D Success	Expected Value of R&D Assuming 0.5 Probability of a Price Shock	Annual Willingness to Pay for R&D
Price Shock	No Price Shock			
590	397	0.1	49	6
590	397	0.25	123	16
590	397	0.5	246	31
590	397	0.75	370	47
590	397	1.0	493	63

Notes: All values are discounted at a 5% annual rate. The assumed R&D investment is for a period of 10 years. The scenario and analysis is based on a hypothetical oil supply curtailment in 2006 and 2007 developed by Greene, et al. (1998). Successful R&D is assumed to increase both the long- and short-term price elasticities of oil supply and demand and the value of these changes are calculated for the period 1995 to 2010. The assumed probability of R&D success ranges from 0.1 to 1.0, and the probability of at least one oil price over a 10-year period is assumed to be 0.5.

Currently, DOE spends ~$0.6 billion per year on R&D judged to be relevant to this oil price shock risk (see Table 3). This investment is much less than what could be justified as prudent insurance. However, this value does not include the

private-sector investment, which includes the investments of the petroleum industry and the transportation industry. These latter investments are at least as large.

Urban Air Pollution. Air quality in most U.S. cities is improving. Cleaner and more cost-effective energy technologies ensure continued improvement in air quality. R&D is the price of these better technologies, and the payoff is reduced pollution at less cost. This risk is a bit different from the previous two energy risks. In this case, we know that air pollution causes damage, although we do not know exactly how to price the damage. Energy R&D can lead to technologies that can reduce the damage at less cost. R&D is not insurance against the probability of an uncertain bad consequence. In this case, the consequence—air pollution—is actually occurring, and the R&D may reduce the cost of mitigation.

Medical costs and time lost from jobs attributable to urban air pollution is certainly in excess of $10 billion per year with that amount estimated for the Los Angeles basin alone (Hall et al., 1992; Romm and Ervin, 1996). Estimates for the health costs of air pollution from vehicles alone are $20–300 billion per year (McCubbin and Delucchi, 1996). To be conservative, we have chosen the lower bound. Suppose that the Partnership for a New Generation of Vehicles (PNGV) and other advanced energy technologies will reduce urban pollution by 20% in 10 years. The present-worth value of those savings (assuming a 5% discount rate) would be greater than $6 billion per year. Americans should be willing to pay up to this amount for R&D to invent the better technologies needed. In this case, the effectiveness of R&D is included in the 20% number in Table 1.

As shown in Table 3, DOE's R&D investment estimated to be relevant to this risk is ~$0.9 billion per year. Hence, this DOE investment seems well justified. The private sector is investing at least as much as DOE to reduce emissions from road vehicles and other energy sources because of government regulations. In fact, the DOE investment is often leveraged by the private sector, for example, in the case of the PNGV. The DOE investment should result in less expensive ways to reduce emissions, as well as more efficient oil use. Even after doubling the $0.9 billion per year, a larger national investment may be warranted.

Energy Disruptions. Current energy infrastructure failures are generally related to natural phenomena such as weather. Due to deregulation in the electricity system, reliability could suffer, but there are many other potential causes, ranging from aging infrastructure to sabotage. The recent events in California have now given us an example of the costs of deregulation on system reliability. Other events in the United States have caused speculation that physical terrorism might be on the rise and a growing dependence on communications and information management in energy-delivery systems has added a new terrorist-related risk. "White collar" saboteurs wielding electronic and computer-based "weapons" pose an even greater threat of disruption than physical assaults on our energy-delivery systems. According to the President's Commission on Critical Infrastructure Protection, "Today, the right command sent over a network to a power-generating station's control computer could be just as effective as a backpack full of explosives, and the perpetrator would be harder to identify and apprehend. The rapid growth of a computer-literate population ensures that increasing millions of people possess the skills necessary to consider such an attack."

Perhaps the most pervasive, yet subtle factors in the reliability of energy-delivery systems are the impending pressures of competition and new regulatory requirements. Although electric loads have increased at about 2% annually over the last decade, very little capacity has been added to the transmission systems during this time. This construction hiatus has been attributed in part to siting difficulties; but, at costs approaching $1 million per mile, capital has also been a factor. Consequently, desires to increase asset use and cut costs can cause delivery systems to be operated much closer to their design limits or in ways for which the systems were not designed, and they can thus raise the exposure to disruptions. This exposure is compounded because, with current technology, one rarely knows where the limit truly is.

Here we concentrate on electricity-supply system disruptions. Electricity outages in the United States are estimated to cost more than $26 billion per year (Hof, 1991). It is not clear what incentives deregulation will create for electricity providers to take steps to improve reliability, but it is not obvious that providers will be able to recover the full value of R&D investments. The benefit is captured by consumers, but are there adequate mechanisms for them to pay the added cost? The role of government may be to encourage the necessary investment through regulations or other policies and to support or motivate the needed R&D. Similar arguments apply to other parts of the energy system.

If, over time, better and more resilient technologies [including enhanced systems monitoring, analysis, sensors, and control devices; advanced operating and maintenance techniques; improved and hardened information systems; new energy storage and generation (including on-site applications); expanded energy-load management; and new materials] can be developed and put in place, society should be willing to pay some fraction of $26 billion per year to do the necessary R&D. In fact, all indications are that the cost and probability of disruptions are both increasing as the infrastructure ages and is asked to do more. Also, some small fraction of such outages in the future may be the result of sabotage or terrorism, and better technologies may reduce that risk. Suppose these better technologies may reasonably reduce the cost by 10–30% or $3–9 billion per year in 10 years. The effectiveness of R&D success is arguably greater than 10%, so at least $0.4–1.2 billion per year in R&D investment to invent cost-avoidance technologies seems justified in current dollars. In Table 3, the enumeration of R&D expenditures judged to be relevant to energy disruptions other than oil price shocks is estimated to be ~$0.3 billion for fiscal year 2000. However, only a very small portion of this R&D is addressed exclusively or primarily to energy disruption and there is no systematic R&D program within DOE for this purpose. DOE is addressing this R&D inadequacy in its 2001 budget submission.

The Insurance Value of Energy R&D

For the four energy risks, the total potential insurance value of energy R&D is at least $17 billion per year. However, the actual value is less because advanced technology developed that is relevant to one risk may also contribute to another. For example, the PNGV contributes importantly to three of the four risks. (Of course, it must be conceded that some R&D relevant to one risk may be counterproductive for one or more of the others. However, it doesn’t really matter because such technologies may prove useful depending on circumstances.) A rough estimate of this overlap can be obtained by observing that the current DOE

R&D investment is about $1.6 billion per year, but the total of the R&D relevant to each of the four risks sums to $3.0 billion—about double the actual budget. Hence, a rough estimate of the total amount the country should be willing to pay for R&D as insurance is $17 billion divided by 2 or about $8.5 billion per year. Thus, the federal government's investment of $1.6 billion is clearly justified for its insurance value alone. This result seems robust even if the relevant private-sector investment is much more than the government is investing.

The Spinoff Value of R&D

One risk to the U.S. economy is that it will not be competitive in the world market for energy technologies. Over the next 15–20 years, the market may grow to as much as one trillion dollars per year (PCAST, 1999). The profits on these sales might be as much as 20% or $200 billion per year. If the U.S. market share can be 10–20%, this would be $20–40 billion per year as U.S. profits. Suppose a 500% return on an energy R&D investment is required, then the U.S. private sector should be willing to invest $4–8 billion per year to capture its share of these profits. Although not all of this profit would be directly from R&D, substantial R&D is required to capture this future market.

At present, we leave this sort of risk to the "invisible hand" and the working of the "free" market. Some argue that competitiveness is no business of government except to ensure a level playing field and the "freeness of the market." Under these circumstances, the private sector surely can take care of itself. Nevertheless, one of the spinoff benefits of public-sector investment in energy R&D as insurance against societal risks is that the economy is the benefactor—it becomes more competitive. After all, many other countries face the same risks, and if the United States is successful in developing better technologies for reducing these risks, those technologies are likely to be attractive in the global market. The technologies are also likely to be attractive to developing nations and, as such, will contribute to the development of the poorer countries of the world.

Another spinoff benefit is obvious but important. R&D success not only reduces the cost of risks, but it should markedly reduce the cost of or improve energy services to the U.S. economy. For example, one estimate is that the cost of reducing greenhouse-gas emissions can be substantially offset by the reduced cost of energy services from using advanced, more efficient technologies (Brown and Levine, 1997; Brown, Levine, and Short, 2000).

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