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U.S. DEPARTMENT OF ENERGY INVESTMENTS IN NATURAL GAS R&D

by

Ronald J. Sutherland

Argonne National Laboratory
370 L'Enfant Promenade, S.W., Suite 702
Washington, DC 20024

Phone (202) 488-2412

ABSTRACT

U.S. DEPARTMENT OF ENERGY INVESTMENTS IN NATURAL GAS R&D: AN ANALYSIS OF THE GAS INDUSTRY PROPOSAL[1]

The natural gas industry has proposed an increase in the DOE gas R&D budget from about $100 million to about $250 million per year for each of the next 10 years. The proposal includes four programs: natural gas supplies, fuel cells, natural gas vehicles and stationary combustion systems. This paper is a qualitative assessment of the gas industry proposal and recommends a natural gas R&D strategy for the DOE. The methodology is a conceptual framework based on an analysis of market failures and the energy policy objectives of the DOE's (1991) National Energy Strategy. This framework would assist the DOE in constructing an R&D portfolio that achieves energy policy objectives. The natural gas supply program is recommended to the extent that it contributes to energy price stability. Stationary combustion programs are supported on grounds of economic efficiency and environmental quality. The fuel cell program is supported on grounds of environmental quality. The natural gas vehicle program may potentially contribute to environmental quality and energy price stability. The R&D programs in natural gas vehicles and in fuel cells should be complemented with policies that encourage the commercialization and use of the technology, not merely its development.

[1]Work supported by the U.S. Department of Energy, Office of Policy, Planning and Analysis under contract W-31-109-Eng-38. The comments of Ken Malloy are appreciated.

"And finally, the seventh action is a totally new focus on natural gas R&D within DOE". Deputy Secretary of Energy, Henson Moore (10/14/91)

1. INTRODUCTION

The National Energy Strategy (NES) emphasizes that the Department of Energy's (DOE) civilian R&D budget should be allocated with the objective of contributing to the national energy policy goals. These goals include: energy security, environmental quality, economic and energy efficiency, securing future energy supplies and fortifying scientific foundations. Present R&D strategy differs from the long-term high-risk strategy of the previous Administration by its willingness to support short term technology development. Historically, the DOE energy programs have provided minimal support for research and development in natural gas and have instead emphasized electricity generating technologies.[2] In the DOE and in Congress there is significant sentiment that natural gas is the fuel of the 1990s and beyond. The DOE has increased its R&D budget on gas programs from $92.7 million in 1991 to a proposed $108.1 million in 1993. A high level of funding of natural gas R&D would reflect a significant change in energy policy from previous years.

The gas industry has responded to this new opportunity by proposing a ten year DOE funding program in natural gas R&D in the amount of $2.5 billion. The proposed R&D is to be in four programs: natural gas vehicles, fuel cells, natural gas supplies and stationary combustion systems. Section 2 presents a brief overview of the proposed funding levels.

A DOE R&D program for natural gas, as well as all other energy programs, should be based on economic criteria for efficient Government investments. These criteria are developed and used to make qualitative recommendations on the gas industry proposal and on current DOE programs. A more quantitative analysis is suggested before a major funding commitment is made.[3] This qualitative analysis identifies those programs where potential benefits may exceed costs. R&D programs are given a preliminary recommendation for Government support when they meet three conditions: (1) the program

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[2]The history of DOE funding and an analysis of DOE R&D policies is reviewed in, Ronald J. Sutherland "An Analysis of the U.S. Department of Energy's Civilian R&D Budget," The Energy Journal, Vol. 10, No. 1, May, 1989, pp. 35-54.

[3]A quantitative analysis would attempt to estimate the incremental dollar benefits that would accrue from the increment in spending. Estimating environmental and energy security benefits due to R&D is, of course, difficult. Estimating the base case level of spending (at the subprogram level) by the DOE and by industry is more challenging than would first appear.

addresses a market failure, (2) the program contributes to an energy policy goal, and (3) Government spending does not displace or "crowd out" private spending. These criteria are developed in detail and used to assess the gas industry proposal. The appropriate role of Government in funding R&D derives from the conditions when private markets fail to make efficient investment decisions. As developed in Section 3, the three "market failures" that apply to energy markets are public goods, externalities and the lack of a market for national insurance. These three market failures are the basic underpinning for an efficient Government energy R&D strategy.

The proposed programs are assessed in terms of their potential contribution to energy policy goals. A model of energy price volatility is developed in Section 4 and used to indicate the type of investment that would contribute to energy price stability. The energy and economic efficiency policy criteria are discussed in Section 5. Economic efficiency is defined in terms of reduced life-cycle costs. The proposed R&D programs may enhance economic efficiency by producing external benefits that reduce industry costs. Section 6 includes a brief overview of air emissions and the potential of the proposed natural gas programs to reduce these emissions. A summary of the conclusions is presented in Section 7.

2. THE INDUSTRY PROPOSAL

The natural gas industry has proposed that the Department of Energy increase its R&D budget in natural gas to about $250 million per year from 1992 through the year 2001, for a total budget of $2.5 billion (in 1992 dollars).[4] The industry proposal is a request to the DOE to sponsor R&D in four areas: stationary combustion systems, gas supply, natural gas vehicles and fuel cells. Table 1 is reproduced from the industry report and it defines the annual proposed budget for each of the four programs. Each program contains from four to six subprograms and each of the subprograms contains some activities. The industry proposal includes an annual funding request for each of the several subprograms and activities. A one page discussion of the needs and benefits of each activity and its technical scope is provided by the industry. The discussion usually relates an activity to a particular energy policy goal. An improvement in air quality is the most frequent benefit, but energy security and energy efficiency often appear.

The goal of the proposed natural gas vehicle (NGV) program is to contribute to the commercialization of natural gas vehicles. One subprogram proposes large demonstration efforts of various vehicle types. These vehicles are conversions to natural gas from standard gasoline driven vehicles. Most NGVs that have been developed and tested are retrofit of conventional vehicles. An R&D effort is proposed for advanced refueling and advanced

[4] The current draft form of the industry proposal is "U.S. Department of Energy Ten Year Funding Recommendations by the Natural Gas Industry" July, 1991, and is available from the American Gas Association in Arlington, Virginia.

storage, which are to overcome two of the technical limitations of NGVs.

The purpose of the gas supply R&D program is to develop new technologies and scientific information that will facilitate an increase in the long run supply of natural gas. The proposed subprograms are to develop a technology or type of scientific information that will lower the costs of discovering new reserves or the costs of recovering proved reserves.

The proposed fuel cell program is intended to contribute to the development and market entry of four fuel technologies. Fuel cells use a chemical process rather than combustion to produce energy. Three of the fuel cell technologies are intended to produce electricity. The fourth, the polymer membrane fuel cell, has the potential of being used in transportation vehicles. The phosphoric acid fuel cell is currently at the commercialization stage. The industry requests that DOE support market entry for this technology by purchasing several units for Government facilities and thereby reducing production costs.

The objectives of combustion system/emission control research are to encourage the development of low emission burners, burner systems and post-combustion controls with applications in electric generation plants, industrial processes and commercial and residential applications. The focus is on reducing emissions and improving energy efficiency, but with a wide range of applications.

The industry proposes an increased budget for DOE R&D, but it contains no information about existing R&D programs by the DOE and the gas industry. Table 2 depicts the FY 1992 budgets of the Gas Research Institute (GRI) and of the DOE's natural gas programs. GRI currently funds R&D efforts in each of the four areas in the industry proposal, but not in each of the various subprograms. The GRI natural gas vehicle program includes advanced storage and refueling systems and several other activities that may overlap with those in the industry proposal. The GRI spends about one-third of its R&D budget on natural gas supply enhancement. The gas industry proposal is unclear whether this level of industry spending was considered in proposing a high level of DOE spending. DOE's decision to invest in R&D must, however, be based on existing levels of private sector investment.

The DOE currently has programs in each of the four areas in the industry proposal. The gas supply and fuel cell programs are in the Office of Fossil Energy (FE). The alternative fuel vehicle program and industrial conservation programs are in the Office of Conservation and Renewable Energy (CE). The DOE's investment in fuel cells is about at the level requested by industry level for 1992. The DOE currently has a small NGV program ($5.7M) relative to the industry proposal. A more detailed examination of the budgets revealed that the DOE's NGV program reflects different priorities than proposed by the gas industry.

This brief review indicates that the four programs proposed by the industry already receive a level of support by GRI and by the DOE. An assessment of the industry funding proposal requires first an understanding of the present level of public and private investment in each of the proposed areas, second, estimates of the expected accomplishments of this base case funding and third, an estimate of the expected results of increased funding.

TABLE 1
NATURAL GAS INDUSTRY / DOE R&D INITIATIVE
SUMMARY

(1992 $ Million)

PROGRAM	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL
Stationary Combustion Systems	76	80	86	90	91	95	100	101	103	103	925
Natural Gas Vehicles	27	36	41	45	45	45	43	38	28	28	376
Fuel Cells	62	73	74	72	70	70	70	70	70	70	701
Gas Utilization Total	165	189	201	207	206	210	213	209	201	201	2002
Gas Supply Total	50	54	54	54	54	54	56	58	58	60	552
TOTAL	215	243	255	261	260	264	269	267	259	261	2554

TABLE 2

NATURAL GAS R&D BUDGETS OF THE GAS RESEARCH INSTITUTE (GRI) AND DEPARTMENT OF ENERGY (DOE) (FY 1992 IN $ MILLIONS)

PROGRAM	GRI	DOE
Stationary Combustion Systems	$74.8	$14.8
Natural Gas Vehicles	7.3	5.7
Fuel Cells	0.8	60.6
Gas Utilization Total	82.9	81.1
Gas Supply Total	58.6	13.2
TOTAL	177.6*	94.3**

Notes: The GRI stationary combustion systems is actually all end-use R&D other than fuel cells and natural gas vehicles. *The GRI total also includes $30.75M for gas operations research and $5.4M for crosscutting research. **The DOE total also includes $3.2M for a gas-to-liquids program.

Source: The DOE numbers were obtained from internal DOE documents. The GRI numbers were obtained from GRI (1991 pp.38-39).

3. MARKET FAILURES

This section develops part of a conceptual foundation to determine the appropriate role of Government in sponsoring energy R&D. Funding energy R&D by the DOE may improve economic efficiency and contribute to national energy policy goals when private markets fail to provide an appropriate amount or allocation of funding. The inefficiencies caused by market failures are suggested to be the appropriate underlying rationale for DOE energy R&D investments. Private markets undertake research to the extent that benefits are appropriated by the private sector and these benefits exceed the costs. Market failures occur when the social benefits of R&D are not totally reflected in the investment decisions of the private sector, resulting a less than desirable level of investment. The non-appropriability of part of the benefits of R&D is the basic principle that gives rise to the potential merits of Government support.

Some benefits of natural gas R&D are external to individual firms and are shared by the gas industry, including its customers. Other benefits are external to the industry and are shared by the general public. The Gas Research Institute sponsors R&D that is in the collective self interest of its members and its customers. (The Electric Power Research Institute performs a similar function for member electric utilities.) The annual budget of GRI is about $200 million. To the extent that the industry research institutes are unable to fund R&D that reflects industry benefits, Government can assist in such funding. R&D benefits that are external to the industry are those that accrue to the general public and include primarily environmental quality and energy security. External benefits that accrue to the public are probably larger than the external benefits that accrue to the industry and are not captured by industry funding.[5]

Three market failures are discussed that apply to energy R&D and result in external benefits.[6] Private markets fail to allocate R&D investments efficiently in the case of public goods, externalities and in providing national insurance. In each of these cases the marginal social benefit of the Government sponsored R&D may exceed its marginal cost. The fundamental point is that private markets may fail to make sufficient investments in R&D because some benefits cannot be appropriated by those making the investments. The task of this study is to identify the proposed natural gas programs that have large external benefits that could be realized from additional Government support. These market failures are not unique to energy markets. The Congressional Budget Office (1984, p. 10-11) notes that Federal support for R&D is justified by "...two distinct types of market failure", externalities and public goods. This position has actually been part of accepted economics for decades. The present study simply applies the analysis to energy R&D markets.

Public Goods[7]

Public goods are consumed collectively, not individually as are most goods. The joint consumption of public goods by several consumers means consumption by one person does not reduce the amount available to others. An important characteristic of a public good is that non-payers cannot be excluded from the benefits of the good. Examples include

[5]External industry benefits generally result from increased efficiency, but such efficiency has a macroeconomic benefit in the form of enhanced economic productivity, economic growth and improved international competitiveness.

[6]These market failures and their implications with respect to energy R&D are discussed in Sutherland (1989).

[7]This section and the following section on externalities benefitted from Robin W. Broadway and David E. Wildasin, Public Sector Economics, Little, Brown & Company, Boston, 1984.

national defense and basic research. The results of DOE's basic research, which include general science and basic energy sciences, are public goods. Their benefits are dispersed widely and quickly through the scientific literature at essentially a zero marginal cost to additional users and the user does not reduce the amount available to others. The cost of distributing the results of research to a marginal user is essentially zero. The cost of an additional consumer using the research results is also zero. When the marginal cost of a good is zero, its efficient price is also zero. However, the private sector is unwilling to produce and distribute a good at a zero price. If the good were priced, that price would exceed the marginal cost of distributing the good to additional users, which is economically inefficient. Economic inefficiency results when marginal external benefits of distributing the good exceed the costs and the private sector has insufficient incentive to distribute the good.

Private markets produce a less than economically optimum amount of research because they cannot always price the result and exclude consumption. However, even where pricing of research results is feasible, economic inefficiency would still result. Where the marginal costs of distributing research results to additional users is zero, an economically efficient price is also zero. DOE funding of such research and its distribution at a zero price can promote economic and energy efficiency.

Basic research is an obvious example of a public good; but technology development, demonstration and field testing may contain an essential component of a public good. The demonstration of a new product produces information about the economic and technical feasibility of the product in a real world environment. The information has value to potential producers and users of the product and to producers of competitive products. This information may be a public good that the private markets have insufficient incentives to disseminate. For instance, the natural gas industry collectively, through the Gas Research Institute, funds natural gas vehicle development and field testing. The results of such demonstration programs also have value to DOE policy makers, to transportation planners and researchers and to manufacturers of vehicles that compete with natural gas vehicles.

The significant point is that some benefits of such programs are external to the natural gas industry. If the information gained from such a program were distributed at a zero price, the gas industry would have no incentive to distribute it. If a price could be levied for the use of such information, the private sector would distribute less information than if the price were at the social marginal cost which could be zero. The private sector will, in general, underinvest in R&D when the product is information that could be useful to third parties at negligible distribution costs.

The practical importance of the above result merits a restatement. When the product of R&D is information of economic value, the private sector may underinvest in producing this information. More seriously, private markets will not disseminate information at its true marginal cost. A potentially useful role of Government is the production and dissemination of R&D information of potential economic value. The Gas Research Program of the Office of Fossil Energy (DOE) includes two activities that are specifically intended to disseminate scientific information. One activity is data base consolidation and maintenance and the other is the compilation of gas atlases and reservoir classification (DOE April 1990, p. 17). More broadly though, a primary objective of DOE's natural gas research program is "...to assure the availability of information..." (p. 12). The gas industry proposal includes support for developing a resource data base that includes regional natural gas atlases. The objective is "to provide producers with information needed to more efficiently develop reservoirs..." (AGA, p.24). These activities involve the Government support of a public good, that may have substantial economic benefits, but would not otherwise be supported by the private sector.

Externalities

Externalities are benefits (or costs) resulting from producing or consuming a good that accrue to a third party and are not priced. An externality generally cannot be priced and therefore the third party cannot be excluded from the benefit by the market price. The inefficiency results because the private sector equates private costs and benefits at the margin, and the social benefits exceed the private benefits. The private sector will underproduce a good that has external benefits. Typical textbook examples of external benefits include the discovery of knowledge or inventions and the training of labor. These activities are likely to result in benefits received by others, where these external benefits are not part of the decision-making process by the producing firms. For instance, in the case of technology development or demonstration, firms not sponsoring the activity can receive some of the resulting information without paying for it and can thereby make their own business decisions at reduced costs.

The benefits of R&D - defined here to include research, development and demonstration - may accrue to firms in both competing and complimentary industries. For instance, successful demonstration of natural gas vehicles could benefit firms that produce products to be used with such vehicles. Demonstrated evidence on cost per mile and other performance characteristics of such vehicles provides valuable information to the industry that is developing electric vehicles. The natural gas industry has an incentive to fund natural gas vehicle demonstrations only to the extent that the marginal benefits to this industry exceed costs. However, benefits of such demonstrations may accrue to the entire alternatively fueled vehicle industry. The environmental benefits and energy security benefits of natural gas vehicles are external to the entire natural gas vehicle. The private sector will therefore underinvest in the development of such vehicles. Government support of the development of this technology can potentially achieve external benefits that exceed costs.

This discussion of externalities and public goods does not make a clear distinction between them. Analytically, public goods and externalities are similar; the difference is one of degree. Almost all the benefits of a public good accrue to the public and a firm may have no incentive to produce such a good, e.g., national defense. When a firm produces a good that has spillover benefits to third parties, that benefit is an externality. The firm therefore has an incentive to produce the good, but not at an economically efficient level. For purposes here, we are not concerned with the distinctions between public goods and externalities. We are concerned with external benefits and whether they accrue primarily to the industry or to the general public.

When external benefits accrue to the public they are likely to be larger than when they accrue to an industry. Some of the proposed gas programs could produce significant benefits beyond the gas industry. These benefits are likely to be energy security and environmental quality. The externality that typically accrues to the industry is the production and dissemination of technical information that reduces the costs of developing technologies and thereby encourages innovation.

Collective Insurance

The oil price increases during the 1970s demonstrated the vulnerability of the U. S economy to world oil prices. The macroeconomic costs of these price changes reflected the non-existence of national insurance against energy supply risks. Private markets may provide an efficient level of personal insurance, such as mortgage, fire, auto etc. Private markets do not provide insurance against national contingencies, such as defense emergencies and energy price shocks or supply disruptions. Energy security benefits resulting from energy R&D are an external benefit not likely to enter into the decision-making calculus of the private sector.

Energy price stability has an external marginal benefit just like public goods and externalities. If R&D provides information that results in reduced volatility of energy prices, it provides an external marginal benefit that will not be considered by the private sector. Some energy investments become economically feasible only if future energy prices are unexpectedly high. Investments in such technologies have low expected discounted benefits to the private sector and will not be developed. However, such an investment may reduce energy price risks. From a public perspective, ensuring against energy price shocks is a reasonable objective.

The National Energy Strategy (DOE, 1991) develops five national energy policy goals: achieving greater energy security, enhancing environmental quality, fortifying foundations, increasing energy and economic efficiency and securing future energy supplies. The latter two goals have been combined into the goal of promoting economic growth. These policy goals recognize that private markets sometimes fail to allocate energy resources efficiently and Government policy is warranted. In fact, energy policy goals reflect specific market failures. The goal of energy security reflects the history of energy insecurity, but also the fact that private markets do not provide adequate protection against volatile world energy prices. The goal of environmental quality reflects the existence of negative externalities - costs imposed by producers and consumers of energy, where the price does not reflect total social costs. The goal of fortifying scientific foundations recognizes that basic research is a public good and hence a responsibility of Government. Improving efficiency contributes to economic productivity, which in turn enhances economic growth and international competitiveness.

The DOE has made a formal commitment in its National Energy Strategy to allocate its R&D budget with the objective of achieving the energy policy goals. This commitment is a milestone, because at least conceptually, it defines the variables in an objective function that ca suggest an efficient portfolio of R&D investments. DOE R&D programs should now be assessed in terms of reducing market failures, but more explicitly in terms of their contributions to energy policy goals that would not otherwise be achieved by the private sector.

4. ENERGY PRICE STABILITY

The NES recognizes that the U.S. economy is vulnerable to world oil price changes. Oil vulnerability has been defined in previous years to reflect the share of oil imported, or, the share of oil imported from OPEC. Supply restrictions from the Middle East have been the precipitating cause of past oil price shocks and perhaps the most likely cause of future price increases. Supply restrictions affect the world oil price, which in turn affect the macro performance of the U.S. economy. Energy security refers to the vulnerability of the economy to the effects of energy price shocks. According to the NES, "Energy security is measured by the expected economic damage the Nation will suffer from energy supply disruptions over a given period of time" (DOE, 1991). This measure of energy security correctly reflects the probability of an oil price shock, its intensity and its expected duration.

The present analysis considers only one component of energy security, namely the volatility of energy prices. R&D investments that reduce energy price volatility also contribute to energy security, although other policy targets could also achieve this result. Energy price stability includes a stable price of natural gas and electricity, even though each fuel is produced for the most part domestically. Electricity prices are not only influenced by fuel prices, but historically were affected by capital costs, particularly of nuclear power plants. The goal of energy security refers broadly to the total costs of energy services; however, this analysis is limited to oil and gas prices.

The insurance provided by natural gas R&D programs against oil price changes depends on the nature of the price change throughout the NES planning period through the year 2030. One possible oil price scenario is a drastic, but short term (1 to 2 year) price shock followed by a return to a long run base case trend. Private markets fail to provide insurance against the consequences of a short term oil price shock.[8] Effective insurance against the consequences of such a price shock requires that the investment have a market impact while price rise. For instance, assume that natural gas vehicles achieve a significant

[8]The Strategic Petroleum Reserve is specifically intended to reduce the consequences of this type of oil price change.

market share prior to an oil price shock. Energy price stability has been achieved to the extent that an oil price increase leaves the operating cost of these vehicles unaffected. If these vehicles were not in operation, but only in the development stage, they would not have provided insurance against a short term oil price shock.

A different scenario of energy price volatility is a repeat of the historical experience of the 1970s, which is a significant rise in the price of oil over a several year period, followed by a decline in its price. The Strategic Petroleum Reserve is limited in offsetting such price movements and is not designed for this purpose. Energy R&D can be designed promote energy price stability by reducing the economic impact of such price movements. Some energy R&D investments will not ensure against short-term price increases but will provide protection against medium and long term price increases. Defining the nature of energy price change that is the target of energy R&D therefore becomes important.

Some Government R&D investments are only economically feasible at a time of high oil prices. After such a price increase, these investments require additional time to penetrate the market and substitute for oil. These investments will not ensure against short term oil price increases, but will ensure against long term oil price increases. For instance, gas supply R&D that contributes to an increase in gas reserves at \$3 to \$4/mcf may not be appealing to the gas industry with current wellhead prices near \$1, but would provide protection against long term oil price increases. With an increase in oil prices, several sectors would substitute gas for oil, putting upward pressure on gas prices. The availability of \$3 to \$4/mcf gas would limit the overall energy price increase. As another example, suppose that natural gas vehicles were economically viable with higher oil prices, but failed to achieve a market share at current prices. In this case, oil prices would first have to increase to encourage use of the vehicles and then the vehicles would have to obtain a sizeable share of the fleet. The time lag limits the effectiveness of the investment to defend against long term oil price increases. Investing in technologies that are only feasible at a future time of national need is a legitimate and important function of Government. However, an investment that provides protection against short term oil price shocks, as well as long term oil price shocks is preferable to a similar investment that ensures only against long term price changes.

An energy price volatility model is constructed to estimate the potential contribution of natural gas R&D programs to energy price stability. This model is developed in a separate paper and is only summarized here. The purpose of the model is to indicate the potential contribution of gas R&D programs to reduce energy price volatility. The analysis is concerned only with oil and gas prices, hence the appropriate energy price is a weighted sum of these two fuel prices. The price of energy can be expressed in equation form as

(1) $\text{Price of Energy} = w_1 \text{Price of Oil} + w_2 \text{Price of Gas}$

where $w_1 + w_2 = 1$ and the weights (w_1 and w_2) are the share of each fuel in total energy (oil plus gas) consumption. The price and quantity of the fuels are measured in common units, such as Btu. Using 1990 data for the aggregate U. S. economy, oil accounted for 63.4 percent of the total consumption of the two fuels. Equation (2) is estimated as

(1') $2.39 = .634 x $3.05 + .366 x $1.24,

which asserts that the average price of energy (oil plus gas) was $2.17 per million Btu at the wholesale level.[9]

Fuel prices are viewed as a random variable with a probability distribution, where the variance is a measure of fuel price volatility. Energy price volatility can be measured as the variance of the price of energy. A statistical property of random variables is that the variance of the sum of two random variables is the sum of their variances plus twice their covariance. The variability of energy prices can therefore be expressed as the variance of the sum of the variances of the oil and gas prices plus twice their covariance. Using σ^2 as a statistical variance, the equation for energy price variability is written as

(2) σ^2 (Price of Energy) = $w_1^2\sigma^2$ (Price of Oil) + $w_2^2\sigma^2$ (Price of Gas) + $2w_1w_2\sigma_{12}$

where the Btu share of oil and gas are denoted by w_1 and w_2. In this model, energy price stability is obtained by reducing the variance of the price of energy. The algebraic property of this equation indicates that the variability of the price of energy can be reduced by: (1) changing the share of gas relative to oil, (2) reducing the variability of the price of gas (or oil), and (3) reducing the covariability between oil and gas prices.

The historical record of oil and gas prices provides an understanding of the energy price stability that would have been obtained by switching from oil to gas. Historically, oil and gas prices experienced similar trends. The average price of natural gas delivered to consumers was just over $0.55 (per mcf) from the middle 1960's through 1971. This price increased continuously through the 1970's and early 1980's, reaching a peak of $4.67 in 1984. Prices then declined continuously throughout the 1980's (Natural Gas Annual). The refiner acquisition cost of crude oil increased from about $4.00 per barrel in 1973 to a peak of $35 dollars in 1981 and then fell continuously to about $14 per barrel by the end of the 1980's. The timing of the historical oil and gas price changes matches closely, with the increases occurring from 1973 through the early 1980's, followed by price declines. The magnitude of the price changes also matches reasonably well, with the prices increasing by a factor of about 8 and then decreasing by a factor of about 2. One implication of these historical

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[9]All data were taken from, Energy Information Administration, Annual Energy Review 1989, Washington DC, DOE/EIA-0384(89), May, 1990. The input data and their corresponding page numbers are: refinery acquisition cost, $14.22/barrel, p. 151; nominal wellhead price of gas, $1.71/mcf, p. 173; natural gas consumption, 18.95 trillion cubic feet, p. 161; petroleum products supplied, 17.24 million barrels per day, p. 115; oil has 5.8 million Btu/barrel p. 284; natural gas has 1035 Btu/cubic foot.

trends is that the price risk of oil and gas has been of similar magnitude since the 1970s. A consumer of natural gas would have been subject to about the same price risks as a consumer of oil. Secondly, diversifying from oil to gas, at least historically, would not have significantly reduced overall energy price volatility.

The historical correlation between oil and natural gas prices is explained in terms of causation. Oil prices are determined on a world market. In contrast, natural gas prices in the U.S. are determined by domestic supply and demand. As noted by Hay (1990, p. 19), oil prices are generally considered a predominant variable in influencing the supply and demand for gas. A change in the world oil price affects the domestic demand for gas and hence its price. For instance, an increase in world oil prices results in the substitution of gas for oil, primarily in the industrial and electric utility sectors. This increase in the demand for gas causes its price to rise. The extent of the increase in the price of gas depends on its price elasticity of supply. In the short run, the link between gas prices and oil prices depends on the excess capacity to produce gas at current prices. Over a several year period of rising oil prices, the link between gas and oil prices depends on the marginal cost of discovering and producing gas. These costs are affected by Government R&D.

The energy price volatility model suggests that two of the proposed natural gas programs can contribute to energy price stability, but the other two programs cannot. The sector most vulnerable to fuel price variations is, of course, the transportation sector. The most effective strategy to achieve energy price stability is to reduce petroleum consumption in this sector. The natural gas vehicle program is therefore recommended as potentially important and worthy of further consideration. A natural gas supply R&D program could enhance energy price stability and it would work synergistically with the NGV program. A stable supply price of gas increases the price stability resulting from an NGV program and from other gas utilization programs.

In terms of equation (2), the variability of energy prices in the transportation sector is determined by the variance of the price of oil because this sector relies almost exclusively on oil. Diversifying into an alternative fuel reduces energy price variability in this sector. The extent of the reduction in price volatility depends on the amount of the diversification, the price risk of the alternative fuel and the covariance between the fuel prices. Given the near exclusive reliance on petroleum in this sector, almost any diversification would reduce fuel price risk. The share of gas that minimizes energy price volatility in equation (2) would exceed 50 percent if the variance of the price of gas were less than the variance of the price of oil, which is probably realistic.

The contribution of the natural gas vehicle program to energy price stability requires the use of these vehicles, not merely their development. A NGV contributes to energy price stability by being on the road, not on the drawing board. More specifically, the contribution of NGVs to a short term energy price shock depends on the petroleum consumption that is displaced. The contribution of NGVs to a long term oil price rise depends also on their use and on the adjustment lag required to increase this use. The important policy implication is that achieving the energy price stability with the NGV program requires that the R&D program be complemented with a policy designed to encourage use of the vehicles.

The link between the price of oil and that of any alternative transportation fuel depends on the supply price elasticity of that fuel. In the event of an oil price shock, the transportation sector would experience an increase in the demand for the alternative fuel. If the supply function for this fuel were price elastic, the increase in demand could be met without a price rise. However, if the short run supply curve were price inelastic but the long run supply curve were price elastic, the fuel would provide more long run price stability than short run stability. Achieving energy price stability in the transportation sector requires first, shifting out of oil and second, shifting in to a fuel that can meet a substantial increase in demand without an increase in price. In terms of equation (2), diversifying into natural gas would make a larger contribution to energy price stability if the link (covariance) between oil and gas prices were severed.

Increases in the supply of natural gas may increase its price stability and tend to weaken its link with oil prices. For instance, suppose that an R&D investment resulted in an increase in the amount of feasible gas reserves at current gas prices. (In economic terms, this increase causes the gas supply curve to become more price elastic.) A short or long term oil price increase would result in the substitution of gas for oil and thereby reduce overall energy price volatility. With increased gas supplies, this substitution can occur without significant gas price increases, which further reduces energy price volatility. Some R&D investments in natural gas supplies will not have apparent economic value at current fuel prices, but will only be feasible at higher prices. Such investments may not provide insurance against short term oil price spikes, but may provide security against medium or longer term price increases. The implication is that some R&D investments may be desirable for their energy security value even though they are not feasible at current prices. This external benefit reduces the risk of a market failure and is reason for consideration of support Government funding.

The proposed natural gas supply program is intended to enhance the future supply of natural gas, would reduce the volatility of gas prices and severe the link between gas and oil prices. The gas supply program is recommended as a potentially important strategy to ensure energy price stability. The importance of this point merits restatement. Oil price volatility affects directly the transportation and industrial sectors. The residential, commercial and electric utility sectors are not highly oil dependent. (Most oil use in these sectors is concentrated in the Northeast.) However, oil prices have affected gas prices and gas is used extensively in the residential, commercial, industrial and electric utility sectors. Energy price stability is enhanced in these sectors by severing the link between oil and gas prices.

The natural gas R&D programs that provide insurance against long term oil price increases include both gas supply research and the development of natural gas vehicles. In addition, the NGV program would contribute to reducing the impact of oil price shocks to the extent the vehicles were in operation. Funding natural gas technologies used to generate electricity is not recommended on grounds of energy price stability. Substituting gas for oil in this sector does not improve energy price stability because only 3 percent of the electricity is generated with oil. The DOE currently supports a diversified set of electricity generation technologies and further diversification is likely to yield negligible benefits. End-use gas technologies that substitute for electricity are also not supported here on grounds of energy price stability. Gas technologies that displace oil in the transportation or industrial sectors can contribute to energy price stability. Displacing oil in the residential and commercial sector has lower potential energy price stability benefits.

The conclusion that gas supply R&D and a NGV program would enhance energy price stability appears non-controversial, however issues arise in the specific funding areas. The gas industry proposes that the DOE spend roughly $40 million per year on NGVs, whereas the DOE's 1992 budget is closer to $5.7 million. A detailed examination of the respective budgets indicates that the proposed projects by the gas industry (demonstration and storage and refueling research) do not resemble the items in the DOE budget. The gas industry, in its R&D request, provides no estimates of the expected results of the specific investments. The DOE, in its budget review process, also provides no written documentation of the expected payoff of various projects. One implication is that, although a NGV program appears to be socially beneficial, there is no evidence to suggest a level of funding nor composition of the program. Second, the ability to select DOE R&D programs that contribute to NES goals would be enhanced if the expected results of each investment were estimated.

Assessing the natural gas supply program presents similar difficulties. Gas supply R&D is certainly characterized by external benefits in addition to enhancing energy price stability. The gas industry is proposing a DOE funding level of about $55 million per year with no estimation of the increase in gas supplies at various prices. The DOE budget of $13.2 million does not include estimates of expected program results. Additional complications are the current excess supply of gas and depressed prices, the rapid rate of technological change affecting gas supplies and the current gas resource base of at least 50 years. One risk of gas technology R&D is that the results are counterproductive by increasing gas supplies under excess supply conditions. A cost-effective gas supply R&D program requires a particularly thoughtful design so as to increase gas supplies at a time of need and not to make investments that may be counterproductive or have a negligible value.

5. ENERGY AND ECONOMIC EFFICIENCY

Enhancing energy and economic efficiency are major goals of the National Energy Strategy. Several of the proposed gas R&D programs are asserted to enhance energy and economic efficiency.

Programs designed to enhance energy efficiency should not measure efficiency as the

Btu per level of output. The conservation literature frequently asserts that a reduction in Btu/GNP is indicative of an improvement in aggregate energy efficiency. One limitation in measuring energy efficiency in terms of Btu content is that efficiency improvements resulting from fuel switching depend on the definition of energy as primary or delivered. Several of the proposed gas end-use technologies could substitute for electricity using technologies. Such a substitution may require a reduced level of Btu input to achieve the same level of energy service. If energy is measured at the primary level, namely the Btu input to electricity generation, energy efficiency is likely to be enhanced. The Energy Information Administration measures energy as Btu of delivered energy rather than primary energy. By this measurement, the energy content of electricity is reduced by about two-thirds, which represents generation and distribution losses. If energy is measured as Btu of delivered energy, the substitution of gas for electricity results in an increase in Btu usage.

A natural gas (or any other energy) R&D investment cannot be assessed merely on its Btu content of providing energy services. There is no market failure associated with this engineering/cost relationship. Changes in the Btu content of providing energy services offer no implications about the costs of providing these services. Certainly, reducing the costs of providing a given level of energy services is more desirable than changing the Btu content of these services. The view that energy efficiency must be measured in dollar rather than Btu terms is affirmed in an "Executive Order" (Bush, 1991) that defines energy efficiency goals for Federal buildings in terms of minimizing life-cycle costs and that are cost-effective. An investment may be considered to enhance energy efficiency if it decreases the energy costs of meeting a given demand for energy services. Such an investment may, or may not be, economically efficient. Presumably, economically efficient investments that also enhance energy efficiency are more socially desirable than economically efficient investments that increase energy costs, although it is unclear why this should be true.

The proposed gas R&D programs may or may not provide an increase in economic efficiency. First, no engineering data have been presented to suggest that the proposed technologies would provide significant cost savings relative to their competitors. For instance, the fuel cell, when fully commercialized may be competitive with alternative generating technologies, but it has not generally been championed as a cost reduction technology. Secondly, individual firms have adequate incentives produce cost saving technologies. Individual firms and industry research institutes each make significant R&D investments in cost saving technologies. Much of the benefit of reducing costs accrues to firms, the industry and its customers. To the extent that the industry can appropriate the benefits of R&D, its incentives are adequate to obtain an efficient level of investment.

An investment is economically efficient if its present value exceeds its costs, where Government R&D costs are a component of total costs. Present value is estimated as the discounted sum of the reduction in the cost of providing an energy service due to the new technology times the quantity of energy produced over time. When reduced energy costs accrue to consumers, benefits can be measured as the sum of producer and consumer surplus. When energy costs are reduced in the productive economic sectors, other benefits accrue. A reduction in the cost of an input, such as energy, improves economic productivity and enhances economic growth. Enhanced economic productivity also contributes to U.S. international competitiveness. The increased productivity argument has been the classic "externalities" argument for Government support of R&D. These benefits imply that the proposed gas R&D programs merit a technical analysis to determine their possible economic efficiency benefits that will not be captured by industry funding.

A Delphi analysis conducted for the DOE of 60 technologies (Shelton, 1992) concluded that no technologies contribute to economic growth in the short run (prior to the year 2000) and only natural gas supplies and electricity transmission and distribution would contribute to economic growth in the mid term (years 2001 - 2010). Several technologies, such as fusions and nuclear fission, could have a long term effect. Because this is the only evidence available, we conclude that only some DOE gas supply investments may enhance economic efficiency. More importantly though, the DOE should provide the best evidence possible of the present value of cost savings of the technologies that they support.

6. ENVIRONMENTAL QUALITY

Natural gas is a cleaner burning fuel than its competitors, oil and coal. As such, the substitution of gas for these fuels should improve environmental quality. The gas industry supports three of its four proposed programs by their potential to improve environmental quality. This section presents a brief overview of air emissions data with the objective of determining where the proposed gas programs could make major contributions to environmental quality.

The potential to reduce emissions depends in part on the fuel consumption of the economic sectors. Table 3 lists the total 1989 consumption of major fossil fuels and electricity measured as quadrillion Btu of delivered energy. The largest uses of fuel are motor gasoline in the transportation sector and steam coal in the electric utility sector. The industrial sector is a major user of residual fuel oil. These sectors and fuels appear to offer the greatest potential for reducing air emissions. In addition, opportunities may exist for natural gas to reduce emissions by substituting for end use electricity in residential, commercial, and industrial sectors. An environmental improvement would result if the electricity were produced by coal.

TABLE 3

U.S. ENERGY CONSUMPTION, BY FUEL TYPE AND ECONOMIC SECTOR, 1989 (Quadrillion Btu of Delivered Energy)

FUEL	Residential	Commercial	Industrial	Trans.	Elec.Utilities
Dist. Fuel	1.06	0.57	1.21	3.72	0.10
Jet Fuel				3.06	
Motor Gasoline		0.11	0.19	13.75	
Residual Fuel		0.26	9.64	0.77	1.58
Natural Gas	4.91	2.80	8.14	0.00	2.87
Steam Coal	0.00	0.00	1.70		15.96
Electricity	3.09	2.77	3.16	0.02	

Source: 1991 Annual Energy Outlook, DOE/EIA-0383(91)

The potential to reduce emissions can also be inferred from total emissions data. Total 1989 emissions from various source categories are listed in Table 4. The most striking result in this table is the large amount of carbon monoxide emissions resulting from the transportation sector. As seen in the previous table, motor gasoline is the major fuel used in this sector. The obvious implication is that efforts to reduce carbon monoxide emissions should focus on gasoline use in the transportation sector. The environmental benefits resulting from natural gas vehicles must come from their reduction in this pollutant, although reducing nitrogen oxides is also important.

The second component of total emissions results from fuel combustion, with the primary emissions being sulfur oxides and nitrogen oxide. The largest single contributor to these emissions is coal burning by electric utilities. The burning of fossil fuels by utilities accounts for about 65 percent of the SO_2 and about 29 percent of the NO_x. The EPA (1991) reports that 95 percent of the electric utility contribution to SO_2 is from coal fired power plants. About 50 individual coal plants account for about one-half of the coal plant emissions. The DOE currently supports stationary combustion technologies targeted to reduce these emission and the gas industry proposes additional efforts.

TABLE 4

TOTAL EMISSIONS OF CRITERIA POLLUTANTS, 1989
(Millions of Metric Tons)

	TSP	PM_{10}	Sulfur Oxides	Carbon Monoxide	Nitrogen Oxides	VOC
Transportation	1.50	1.50	1.00	40.00	7.90	6.40
Fuel Combustion	1.80	1.30	16.80	7.80	11.10	0.90
Industrial Processes	2.70	2.30	3.30	4.60	0.60	8.10
Solid Waste	0.30	0.20	0.00	1.70	0.10	0.60
Miscellaneous	1.00	0.70	0.00	6.70	0.20	2.50
Total	7.20	5.90	21.10	60.90	19.90	18.50

Notes: TSP is total suspended particulate emissions, PM_{10} proportion of the emissions, VOC is volatile organic compound emissions.

Source: U.S. Environmental Protection Agency (1991).

Natural gas clearly has inherent environmental advantages over alternative fossil fuels. Sulfur, ash, and carbon dioxide emissions are lower for natural gas than for either coal or oil. The greatest opportunity for reducing emissions through the increased use of gas is in the substitution of gas for coal in the utility sector. Application to the residential, commercial, and industrial sectors offers far less potential advantage, since the total energy use and emissions are far less and gas already has a dominant role in these sectors.

The use of natural gas vehicles in place of conventionally fueled vehicles, offers the potential to reduce air emissions, particularly carbon monoxide. Hay (1990) summarizes the results of several studies that support this conclusion. In referencing Durbin (1989), Hay concludes that dedicated natural gas vehicles would reduce total hydrocarbon emissions by about 33-50 percent. Natural gas conversions of conventional engines typically offer a negligible reduction in emissions. The environmental benefit of NGVs depends on the development of a dedicated NGV engine.

This preliminary overview of emissions documents that natural gas produces lower emissions than its two competitive fossil fuels, coal and oil. Three natural gas programs are proposed by the industry partially on grounds of environmental quality. These programs include natural gas vehicles, fuel cells and stationary combustion. These programs are targeted in areas where major environmental improvements coudl be made. However, a justification for additional expenditures should reflect some evidence that a reduction in emissions may result from the increment in expenditures.

7. RECOMMENDATIONS

This section provides a preliminary recommendation of the gas industry proposal consistent with the principles of Government support for R&D developed above. The gas industry proposes a major increase in Government support in each of four areas: natural gas supplies, natural gas vehicles, stationary combustion and fuel cells.

Fuel Cells

Fuel cells are energy conversion devices that convert chemical energy into electrical energy. They are modular and can be assembled into stacks to obtain the desired power output. Fuel cells can be used by electric utilities to generate electricity, but they can also be used by the industrial and commercial sector for on-site power generation and cogeneration. One fuel cell technology, the polymer membrane, is being developed for transportation applications.

This program does not appear to contribute to energy price stability. Fuel cells would enter the market for new and replacement generating capacity. In terms of new capacity, fuel cells will compete with natural gas turbines, coal plants and, in the distant future, perhaps nuclear plants. Fuel cells will not displace oil, because oil plants would not have been built anyway. Fuel cells may displace retired oil generating stations, but these stations would have been replaced by another fuel. The benefit is an environmental one, not an energy security benefit. An energy security benefit would arise if scientific information concludes that burning of all fossil fuels is environmentally unacceptable.

Fuel cells offer an alternative source of generating capacity and as such they may appear to reduce supply risks of electricity. However, the supply of electricity is relatively secure and numerous supply options already exist and others are being developed. A reliable supply of electricity at stable prices is a reasonable goal. In this area, the benefits of energy price stability must be divided between a large number of competing technologies, where the incremental benefit of any single technology is probably not substantial.

Fuel cells produce negligible emissions. As such, fuel cells produce an external benefit because the private sector has limited incentives to produce air emissions below the levels permitted by regulations. The major argument of behalf of Government support for this technology is its environmental benefit. This benefit occurs only partially through R&D, but primarily with each fuel cell unit produced, or more correctly, with each kwh of electricity produced with fewer emissions than would have been produced by the alterative technology. For this reason, a Government policy action that encourages the commercialization and use of fuel cells appears warranted.

Natural Gas Vehicles

The successful development of natural gas vehicles and their commercialization contributes to two energy policy goals and is clearly targeted on market failures. The development and marketing of such vehicles has the effect of improving air quality because gas is being substituted for less clean burning fuels, such as gasoline and diesel. The environmental improvement could occur relatively quickly because the vehicle fleet turns over in about a decade. The potential to achieve a substantial market share quickly implies that benefits can be attained quickly. As gas displaces oil, an energy price stability benefit also occurs, as described above in equation (2). Furthermore, this price stability benefit provides protection against short term as well as long term oil prices increases, because gas has been substituted for oil.

Additional grounds for supporting NGV are that the transportation sector relies almost exclusively on oil and does not have the potential to substitute other fuels. The electric utility and industrial sector use much less oil as a share of their total energy use and these sectors have some capability to switch out of oil. The costs of energy price instability are therefore borne more heavily by the transportation sector than by other sectors. A major improvement in energy price stability cannot be obtained without reducing oil consumption in the transportation sector. This sector is also a major contributor to adverse air quality. Reducing oil use in this sector contributes to two energy policy objectives and in a potentially large way.

The proposed NGV program includes demonstration programs in the amount of $105 million over 5 years, environmental R&D in the amount of $96 million and advanced storage and refueling subprograms totalling $175 million. The demonstration programs would use vehicles with gasoline or diesel engines that have been converted to natural gas. Vehicles with conventional engines, converted to use natural gas, typically do not offer major environmental improvements over conventional engines with low emissions. The future of NGV does not depend upon conversions, but rather upon dedicated NGV's. A dedicated NGV is one designed initially to use natural gas. There are currently more than 15,000 (conversion) NGV's being used in the U.S. Sanders and Moreno (1990, p. 251) report an estimate of 400,000 NGVs being in use worldwide. Given this extensive experience and the limited environmental improvements with NGV conversions, an additional demonstration program using converted vehicles appears hard to justify. The R&D proposed programs that emphasize dedicated NGV's appear more promising.

Saunders and Moreno (1990) estimate the conditions under which NGVs break even with petroleum fueled vehicles. The economic feasibility of NGVs depend on several variables: the type of vehicle, their use (local verses distant delivery), their fueling rate (fast-fill verses trickle fill) and the prices of oil and natural gas. NGVs are more feasible when natural gas prices remain constant in the event of an oil price increase, rather than if gas prices track crude prices. This result, although obvious, supports one of the more important conclusions of this study. A Government R&D program in NGV is justified partially by displacing oil and thereby contributing to energy security. Such a program would be more beneficial if the link between oil and gas prices were severed. An important objective of the gas supply program would be to contribute to gas supplies such that gas prices would not track oil prices. The NGV and gas supply R&D programs therefore work synergistically.

The external benefits of NGV occur with their use, not merely with technology development. The environmental benefit and displacement of oil each depend on vehicle miles driven. A Government strategy that includes support for commercialization and use appears warranted. The DOE's R&D efforts in this area, and in some other areas, will not achieve their potential benefits unless an R&D strategy is complemented by policies that encourage the use of the technology. The level and allocation of funding proposed by the gas industry is significantly different from the current DOE NGV program. The advise of an outside panel of experts on program design and funding would be useful.

The Combustion Systems Program

The gas industry recommends that DOE fund R&D for various stationary combustion systems in the amount of $925 million over the next 10 years. The funding is to encourage development of low emissions burners, burner systems and post-combustion controls that can be used by the electrical generation, residential, commercial or industrial sectors.

Recommendations on this program are particularly tentative because the benefits of the various subprograms are not estimated and current efforts by DOE and GRI at the subprogram level are not yet defined. Probable external benefits of the subprograms can be defined to support preliminary conclusions. The subprograms that are intended to reduce emissions appear to be the best candidates for Government support. Environmental benefits accrue to the general public and are external to the industry. These activities are included in the combustion systems/emissions control subprogram and the industrial process subprogram. The proposed advanced research and technology development subprogram would likely produce the largest "external" benefit to the industry because it focuses on the basic research end of the spectrum. The proposed natural gas cooling program would contribute to the substitution of natural gas for electricity. This program would not enhance energy efficiency, economic efficiency or energy price stability. The environmental improvement requires documentation. The commercialization of gas cooling technologies would have a major economic effect of stabilizing seasonal fuel demand in both the electricity and gas industries, with the benefits accruing to these two industries. The external benefit from developing this technology has not been documented.

Developing technologies for combustion systems may produce external benefits to individual firms that are internalized by the industry. Government suppo rt may contribute to economic efficiency. Private firms have significant incentives to develop more efficient technologies and they have even greater incentives with support from the GRI and Institute for Gas Technology. Justifying additional Government support requires identifying additional external benefits that industry would not otherwise support.

The Natural Gas Supply Program

Government support for natural gas supply R&D is warranted on grounds of externalities (including public goods) and contributing to energy price stability. The price stability argument is most persuasive because private markets have insufficient incentives to provide for national insurance. Gas R&D strategy could be designed to sever the link between gas prices and major oil price increases. Such a strategy would contribute to energy price stability. This strategy would complement GRI's strategy of undertaking short term supply R&D with a goal of discovering and producing $2.50 gas. A DOE goal of contributing to the supply of gas in the $3 to $4 range would provide a resource available at a time of need. Such R&D would not "crowd- out" industry efforts. Such a policy would, in effect, create a "Strategic Gas Reserve" that would serve like the Strategic Petroleum Reserve. The gas, however, would not be purchased, produced and stored. Instead, a relatively small R&D expenditure would simply ensure that a large quantity of gas is available at a time of need.

Some Government support for natural gas supply R&D can be justified on grounds of economic efficiency. The case is more difficult and there are risks that the expenditures have a low payoff. The geological atlases represent a public good. Much of the proposed R&D has benefits external to a single firm, but internal to the industry. These benefits are in the form of increasing gas supplies at existing prices, or, reducing the price of producing gas. However, one of the risks is that supply prices are reduced further when market prices are already low. Current wellhead prices of about $1.00 per mcf are an example. Government efforts to increase the supply of gas under current conditions are counterproductive for the industry and perhaps not in the long run interest of consumers. Low gas prices also tend to counteract Government programs to conserve energy. One risk of gas supply R&D investments is that they are economically successful, even when they are not needed.

The second risk of investing in gas supply R&D is that it displaces private spending. The GRI spends about $58 million per year in this area. Government efforts to obtain additional benefits could result in a decrease in private spending. Efforts to focus a DOE gas supply R&D strategy on obtaining energy price stability would experience neither of the above risks. The main challenge to the DOE is to assess the various gas supply investments and select those with the expected outcome that contributes to this specific objective.

Summary

Government investments in energy R&D are intended to contribute to NES goals and have positive net benefits. As such, Government can support R&D where at least some of the benefits are external, either to individual firms or to the industry. Public benefits are those that accrue to the general public, such as environmental quality and energy security. Industry benefits include externalities and public goods that benefit the industry overall, rather than a single firm. One implication of this study is that the public benefits are likely to be larger than the industry benefits. For one, the industry research institutes, GRI and EPRI support the development of technologies that benefit the industry. In contrast, the industry institutes have no incentive to fund R&D that benefits the general public. These benefits are likely to be larger than industry benefits and the Government has less concern about crowding out private spending. Public benefits are likely to result from the use of a technology, not merely from its development. The DOE should complement its R&D programs with commercialization and demand strategies to more effectively achieve its energy policy goals. The DOE natural gas R&D programs no doubt contributes to the NES and the proposed increase in these programs goals would make a further contribution. Obtaining an efficien set of natural gas R&D investments requires first improved estimates of teh results of the investments and second a portfolio analysis that includes all the DOE energy investments.

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