Briefing Paper

Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity

The National Regulatory Research Institute

March 2005

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EXECUTIVE SUMMARY

Long-term fuel diversification has caught the attention of state regulators and other policymakers. Fuel diversity has the potential to advance socially desirable objectives, such as (1) lower long-term electricity prices, (2) lower electricity-price risk, (3) less dependency on foreign sources of energy, (4) higher electric power reliability and (5) a cleaner environment.

Whether a more fuel-diverse electric sector would achieve one or more of these objectives cannot be taken for granted. Just as important, whether fuel diversity is more effective than other alternatives with similar objectives needs to be analyzed: a focus on fuel diversity as an end in and of itself is misplaced. Achieving more fuel diversity may involve a trade-off between reducing risk and minimizing the price of electricity.

This briefing paper lays out the major arguments for long-term fuel diversification, drawing heavily on portfolio theory and real options theory, each of which has its origins in finance. Specifically, it focuses on diversification in the context of determining the appropriate role of different fuel sources and generation technologies in a resource portfolio. The development of a resource portfolio is applicable to both a vertically integrated electric utility and a utility that has divested its generation facilities.

The paper also provides some observations to assist policymakers, whether they are state officials, federal entities, or industry decision-makers, in contemplating the complex issues surrounding fuel diversity. While compelling arguments can be made for achieving a more fuel-diversified electric sector, how diversification can most effectively be managed poses some hard challenges for policymakers and stakeholders in the regulatory process.

Contents

The author is grateful for the helpful comments of Jeffrey Conopask, Roy Ericson, Robert Keating, Raymond Lawton, Kenneth Rose, Boris Shapiro, William Steinhurst and Vivian Witkind Davis on earlier drafts of this paper.

05-02

The tightened wholesale gas market has increased the intuitive appeal of fuel diversity.

THE CURRENT INTEREST IN FUEL DIVERSITY

The concept of fuel diversity as applied to electric generation has great intuitive appeal, especially in light of the ongoing dynamics in fossil-fuel markets.[1] Specifically, the tightening of the wholesale natural gas market over the last few years has heightened interest by a wide spectrum of stakeholders and policymakers in diversifying the future portfolio of electric generation technologies and fuels. In this paper, "diversifying" refers to the act of deploying a mix of electric generation technologies with different fuel sources. As discussed below, this mix of technologies should be combined in a portfolio accounting for the risks and benefits contained in each technology.

Champions of Fuel Diversity

The champions of fuel diversity have recently encompassed a broad range of stakeholders and interest groups, some of whom were previously opposed to, or at best lukewarm about, diversifying generation technologies and fuels beyond traditional sources. The Edison Electric Institute (EEI) has recently argued that "fuel diversity protects consumers and electric companies from fuel unavailability, price fluctuations, and changes in regulatory practices. It also helps ensure stability and reliability of our electricity supply." A statement earlier this year by the EEI Board of Directors supports "Federal and state energy and tax policies [that] promote fuel diversity and further development of renewable energy, energy efficiency improvements, nuclear energy, and clean coal technologies."[2] The Electric Power Supply Association recommends that fuel diversity be considered an important national goal; specifically, it argues that "the nation's energy security requires the efficient use of all natural resources, both renewable and nonrenewable." The Nuclear Energy Institute argues that "Nuclear power plants provide diversity to any overdependence on fossil fuels and are the only expanding source of generating capability that doesn't contribute to air quality issues with greenhouse gases and controlled pollutants." Finally, as early as 1999, the then Chairman, President, and Chief Executive Officer of American Electric Power, a heavily coal-based utility, wrote in an article that "For the future…a fuel diversity strategy in which advanced fuel technologies compete for efficiency, environmental benefit, and economy will be of paramount importance. Such a strategy must seek to balance the right levels of gas, renewables, nuclear, and coal."[3]

NARUC Leadership

The National Association of Regulatory Utility Commissioners (NARUC) has been a strong advocate of a more diversified fuel mix in electric generation. In various resolutions and in its National Electricity Policy, NARUC has emphasized the importance of encouraging "additional fuel- and technology-diverse supply resources to meet the nation's growing energy demands."[4] It has asked Congress to "encourage environmentally responsible electricity generation and the increased use of renewable energy technologies as a tool to achieve fuel diversity and energy security." A number of commissioners believe that clean-coal and the next generation of nuclear power technologies should be part of any future portfolio of electric resources.

At the NRRI/NARUC Commissioners Only Summit in January 2005, commissioners identified fuel diversity in electric generation as one of the top four issues over the next 12 to 18 months. Commissioners identified a major problem as the absence of a formal and balanced approach to studying fuel-diversity issues, including the salient problem of price volatility. Some commissioners felt that a national energy policy is needed to advance fuel diversity and to provide stronger incentives, for example in the form of tax credits, for the development of some generation technologies.[5]

NARUC has recently received a grant from the U.S. Department of Energy to examine "options available to state utility regulators to manage electricity resources in today's diverse regulatory environments." The project includes conducting workshops and holding a national conference on portfolio management in late 2005.

State Interest in Fuel Diversity

At the state level, interest in weaning the electric sector from its dependency on fossil fuels has proliferated over the past few years. In June 22, 2004, for example, the Western Governors Association issued a policy statement (Policy Resolution 04-13) with the following recommendation: "To maintain Western Governors' commitment to a viable economy and a clean and healthy environment in the West, we need to pursue a national energy policy that will result in a diverse energy portfolio that will include conventional and alternative energy resource development, energy efficiency and conservation."

One reflection of the view favoring less dependency on fossil fuels is the implementation of renewable portfolios standards (RPS) in an increasing number of states.[6] Interest from certain quarters has also risen with regard to the possible expansion of coal-based and nuclear technologies to meet future electricity demands. Overall, a current hot topic of discussion is how to increase fuel diversity in the electric sector. The call for more fuel diversity is being echoed in trade publications and regulatory and energy conferences everywhere.

Part of the explanation for the heightened interest in fuel diversity is motivated, in some cases, by self-interest and the seemingly prevailing perception that fuel diversity cannot be anything but good in the current volatile environment.[7] But perhaps a more satisfying reason is the growing concern that the United States may be heading into rougher times by continuing on a path of relying heavily on fossil fuels for future electricity generation.[8] Few, if any, policymakers and interest groups have publicly opposed the concept of fuel diversity, although they invariably have different visions of what it means and how it should come to fruition.

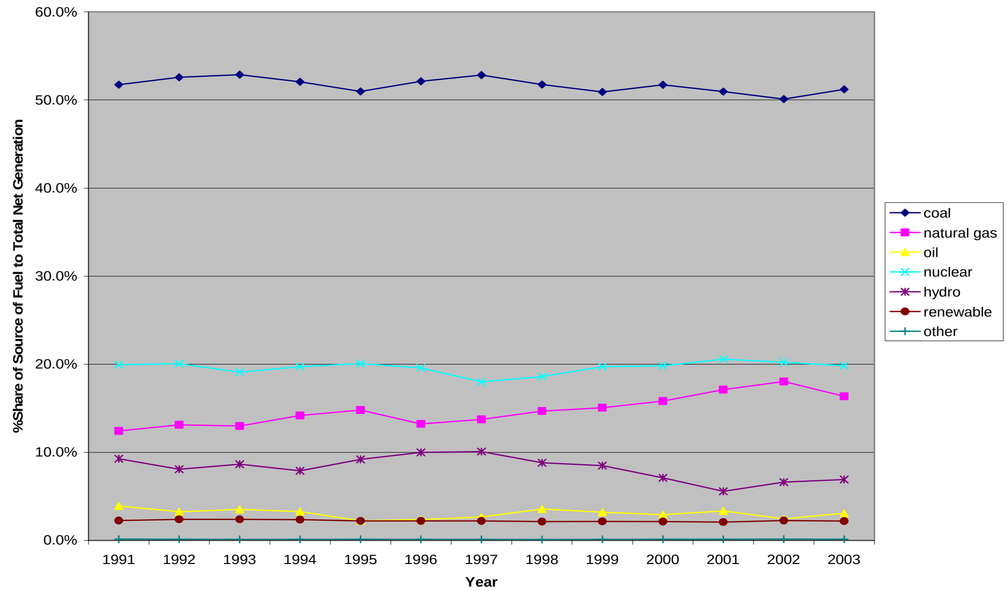
Overreliance on fossil fuels may lead to rougher times for electricity generation.

FUEL USE IN THE UNITED STATES

Since 1978, the United States has seen a dramatic shift in fuel use for electric generation.[9] Over this period, the market share for oil, measured in terms of electric generation, has decreased from 17 percent to around 2 percent;[10] the shares of natural gas and nuclear power have increased, while coal has moderately increased its share. By far, natural gas has been the preferred fuel choice since the early 1990s. What may be surprising to some readers is that share of renewable energy (excluding hydropower) has remained pretty constant (around 2 percent) over the past fifteen years.[11]

Natural gas has been by far the preferred fuel choice since the early 1990s.

Figure 1 shows the composition of electric generation by fuel source over the period 1991-2003. Fuel shares in individual regions of the country vary considerably. For example, in the Midwest coal is used for about 80 percent of the region's electric generation. Fuel shares can also



Source: Author's construct.

Fig. 1. Market shares of individual fuel sources for electric generation, 1991-2003.

dramatically shift over a short period of time. For example, in 1999 gas-fired generation supplied about 16 percent of New England's total electricity requirements, rising to around 40 percent by 2003 and projected to increase to almost 50 percent by 2010.[12] For different economic and policy reasons, some states such as California have a higher degree of fuel diversity for electric generation and power purchases than other states.

The primary justification for fuel diversification is reduction of risk.

According to the U.S. Department of Energy's (DOE's) projections for the next 20 years,[13] natural gas will continue to increase its market share; renewables will modestly increase their share; and coal will continue to reign as the number one fuel for electric generation in spite of its environmental problems. DOE projects that by 2025 fossil-fuel generating units will produce over 75 percent of the electricity in the United States, which represents an increase over the current percentage (70 percent).

Factors Accounting for Fuel Choices

Several factors account for the fuel sources and electric-generation technologies selected by power producers. These include: (1) fuel costs (affected by both fuel source proximity and transportation cost) and operating costs, (2) load profiles of consumers, (3) capital costs, (4) environmental constraints and (5) regulatory statutes, rules and policies. Recently, more consideration has been given to the risk attributes of different fuels and generation technologies.

Most electric utilities have historically relied, to some extent, on fuel diversity to hedge against fuel-price spikes, to maintain system reliability, and to deal with emergency situations. Yet, there are examples of individual utilities heavily relying on one fuel source, some with good results while others arguably not. While long a goal in some jurisdictions, recently fuel diversity has been elevated to a higher status within the resource planning and power procurement processes. Probably, the major reason for this is the dramatic tightening of natural gas supplies since 2000, erasing natural gas as the unequivocally preferred fuel choice for future generation-capacity additions. For example, the post-2000 price volatility of natural gas has stimulated a great deal of interest in other fuel sources that have lower price risk. Probably more than anything else, the risk component of capacity expansion, particularly as it relates to electric price volatility, explains the recent interest in fuel diversity.

The Role of Risk Reduction

The primary justification for fuel diversification lies with the objective of reducing risk, a strategy parallel to investors' diversification of their financial assets to achieve tolerable risk and, at the same time, earn reasonable returns. In the case of electric generation, what exactly these risks are and how they can be quantified are crucial questions facing industry planners and policymakers. These risks are many and different in character. They include technology/design, development/siting, regulation, construction, operating performance, fuel price and supply, demand, dispatch, waste and byproducts, and transmission.

In an important way, the surge in gas-fired generating capacity over the past 15 years can be explained by the perception of higher risks for other sources of capacity. Gas-fired facilities were particularly compatible with a more competitive electricity market that was evolving: they could be built quickly with relatively low capital costs, siting problems were minimal, and they could be built efficiently on a small scale. The combination of relatively low environmental impact, low capital costs, high thermal efficiency, the short construction times of natural gas facilities and their modular feature all contributed to the attractiveness of natural gas as a new source of electric generation starting in the early 1990s.[14]

Major Disruptive Events

One lesson we have learned over the course of the past 30 years is the inevitability of the unexpected. Beginning in the 1970s, several events have radically reshaped the economics and social acceptability of individual generation technologies. The major ones include:

- Organization of Petroleum Exporting Countries (OPEC) price increases starting in the early 1970s
- Three Mile Island and Chernobyl nuclear accidents
- The Public Utility Regulatory Policies Act of 1978 (PURPA)
- The Powerplant and Industrial Fuel Use Act of 1978 (FUA) and its repeal in 1987
- High construction-cost overruns for nuclear plants in the 1970s and 1980s
- Tightening of clean air environmental regulations and laws over the past three decades
- Wholesale power market restructuring starting in the 1990s
- A "gas bubble" from the mid-1980s to 2000, resulting in high availability of cheap natural gas
- Significant tightening of the natural gas market since 2000[15]

What these events have shown is that individual disruptions can abruptly and

Individual disruptions can dramatically shift the rank order of desirability of different fuels.

dramatically shift the rank order of the desirability of different fuels for electric generation. From its inherent risk-reducing character, fuel diversity has emerged as a concept with the potential to mitigate the societal costs of unexpected market and government developments by giving utilities and other generators more flexibility and options in coping with dramatic, and oftentimes unanticipated, events. In today's highly uncertain world, the potential benefits from fuel diversification seem to warrant serious consideration. One major uncertainty is the enactment of future regulations for controlling carbon dioxide emissions. While most industry experts agree that there will be significant controls in the next two decades, when and how strict these controls will be are unknown at this point in time.

Weighing the Risks of Alternative Fuel Sources

All fuel sources for electric generation have risks.

Almost everyone would agree that all fuel sources for electric generation have risks as well as positive attributes. Table 1 enumerates some of these for individual fuels. As shown, there is currently no "silver bullet" in generation technologies and sources of fuel. What makes the present situation perhaps unprecedented, from a historical perspective, is the fact that no one fuel source stands out as the clear choice for the future. Until the spikes in natural gas prices starting in 2000, combined cycle gas technologies (CCGTs) were considered by most industry observers to have minimal risk and were extremely economical; but this line of thinking has eroded as the post-2000 events in the wholesale natural gas market have called into question the attractiveness of natural gas as the primary fuel source for new generation capacity.

All promising generation technologies and fuel sources should be considered.

In contrast to natural gas, traditional coal technologies have low and relatively stable operating costs but raise environmental and siting concerns. As shown in the table, nuclear has its own limitations. For example, nuclear power faces severe barriers, primarily because of radioactive waste management issues and public concern about radioactive exposure from accidents or terrorist attacks. Concerns are also raised over the reliability of renewable energy. For example, the intermittent nature of wind power reduces the dependable value of wind sites, so that the seasonal and time-of-day availability of wind may not always be in sync with peak demand periods; and integrating wind generation safely and reliably into the regional electric power network may offer special challenges. As renewable energy is increasingly relied on, it becomes imperative that it can be counted on as a reliable source of generation capacity. Finally, opportunities for expanding hydropower capacity are greatly limited, and in fact capacity is declining in sections of the country where dams have been removed for environmental reasons.

Use of Diversified Portfolio Strategies

Overall, since no perfect fuel source exists, and at this time not even a preferred fuel source has stepped to the forefront, consideration of all promising generation technologies and fuel sources as candidate elements of a future resource portfolio seems compatible with good planning fundamentals. This approach to resource planning is increasingly being applied by electric utilities in the United States. Specifically, one recent trend is for electric utilities, in some instances with pressure from their state public utility commissions, to give serious attention to diversifying their supply portfolios away from natural gas and other fossil

Table 1: Attractiveness of Different Fuel Sources for Electric Generation

Fuel	Positive Features	Negative Features	Electric Generation 2003 (Percent)
Coal	Abundant domestic coal reserves Emergence of clean coal technologies Low operating costs relative to other fossil fuels	High emissions control costs Siting problems for new plant locations	51
Natural gas	Low construction risk Low environmental damage relative to other fossil fuels Modular construction	High fuel cost volatility High operating costs, especially for gas combustion turbines Drives up gas prices for other users	19
Nuclear	No air pollutants Low operating costs Non-sensitive to world oil prices	Safety concerns High capacity cost with long construction time Disposal of nuclear waste	20
Hydro	No air pollutants Low economic costs	Limited capacity expansion Volatile availability	7
Renewables	Minimal fuel-price risk Environmentally benign Stable or decreasing costs	Intermittency and other reliability concerns Generally high economic costs	2

Source: Author's construct.

fuels and toward non-conventional sources, particularly renewable energy. As noted above, the recent proliferation of renewable portfolio standards in several states illustrates the ongoing concern about the continued dominance of fossil-fuel generation technologies in the foreseeable future.

One example where a diversified portfolio strategy being implemented is resource planning by PacifiCorp, which has pronounced that "a diversified approach fits the need to achieve low cost, low risk and reliable source of energy for our customers while balancing social and environmental concerns. No one energy source is adequate from a cost/risk standpoint to meet the needs of our customers."[16] PacifiCorp also recognizes that resource planning is a dynamic, adaptive process that requires sequential actions in response to changing circumstances. In other words, planning should allow for flexibility in light of uncertainties in markets, technology developments, and government/ regulatory policies. Another electric utility, Xcel Energy, has endorsed what it calls the "balancing act" whereby fuel diversity receives top priority for managing fuel risk and keeping electricity prices down in the long run.[17] Last year, the utility filed a 10-year plan with the Colorado Public Utilities Commission proposing the building of a new coal-fired generating facility (the first built in the state since 1980) and wind-energy facilities. Xcel Energy also plans to add new wind capacity and promote energy efficiency on the consumer side.[18] Other electric utilities have increasingly taken a portfolio approach by evaluating a wide array of generation technologies and fuel sources for possible future development.[19]

As discussed in more detail below, in considering a more fuel-diverse electric sector, industry planners and policymakers should evaluate potential future generation technologies, including immature ones, by applying theoretically sound analytical techniques in the context of a multi-objective framework. Certainly, in view of uncertainties over future

Policymakers should use sound analytical techniques to evaluate future technologies.

market conditions, the commercialization of different generation technologies and prospective government/regulatory actions, it seems sensible to keep all the options open at this juncture. This means that, at the minimum, some development funds should be allocated to each credible technology, without necessarily making significant financial commitments. In terms of government financial assistance, this view suggests that the money should be spread around to all promising technologies, rather than picking winners and losers at this point in time. These technologies include renewable energy, clean coal technologies, nuclear, and natural gas.

THE RATIONALE FOR FOSTERING FUEL DIVERSITY

Cost-Benefit Perspective

The fundamental economic question is whether the benefits of fuel diversity outweigh the costs.

Stripping the different arguments for fuel diversity to their barest, the primary one revolves around the benefits of having a more diversified portfolio (which could include both self-generation and power purchases) to hedge against price, fuel supply, electric reliability, and government/regulatory risks. The fundamental economic question is whether these benefits are expected to outweigh the costs. As with any activity, the justification for fuel diversity must come only after reviewing both the benefits and costs. It cannot be taken for granted that achieving a higher degree of fuel diversity would have net benefits, or is socially desirable, especially if it is not carried out intelligently. Fuel diversity per se should not be perceived as an end, but only as a means that has the capability to generate benefits less costly than other alternatives in achieving the same objectives of fuel diversity.

As an illustration, financial instruments may have lower costs than fuel diversity (which can be viewed as a physical hedge) in reducing price risk to a tolerable level.[20] Fuel diversity may also create costs from the loss of scale economies associated with traditional generation technologies. For example, if fuel diversity results in a smaller coal power plant being built, the average cost of electricity from this plant may be higher than if a larger plant was built. Fuel diversity, akin to insurance protection or hedging, may also result in higher costs from owning and operating a portfolio of power sources that include several fuels and technologies, some of which may not have the lowest expected costs. While today's uncertain environment seems compatible with achieving a higher degree of fuel diversity in the future, such a strategy may impose additional costs that need to be accounted for in resource planning decisions.

Benefits

The main defense for fuel diversity lies with its ability to reduce risks of various kinds. These risks stem from changing market conditions and new government/regulatory actions that can abruptly alter the relative preferences for different fuel sources in electric generation. A more explicit consideration of risks will change the paradigm of resource planning and acquisition in the electric industry. As some analysts have described, the traditional least-cost planning approach involves formulating a portfolio of resources with the lowest expected future cost, constrained by specified reliability standards. In contrast, taking explicit account of risk in a portfolio entails reducing the variance around the future expected cost.[21]

Fuel diversity can produce a variety of benefits:

- Reduced volatility in electricity prices
- Cleaner environment
- Improved electricity reliability
- Reduced risks from new government/regulatory policies
- More flexibility for an electric power system in managing unexpected events
- Overall, a built-in hedge for reducing risks for electric consumers, suppliers and society as a whole

By its inherent nature, fuel diversity increases flexibility and optionality for an electric power system.[22] With more choices, a utility has better capability to adapt to changed conditions. "Better" implies that if unexpected events occur, the utility can respond more quickly and cheaply, and overall lessen the chances of a high-cost outcome, than if the utility had fewer choices. As an example, if the United States enacts strict carbon-dioxide mandates over the next several years, a coal-based utility which had previously committed itself to an aggressive renewable-energy program for acquiring future wind capacity would be in a less precarious position than if it had not. As another example, a utility that made the decision to install dual-fuel boilers could better react to a regional bottleneck in gas transportation. But, of course, the caveat is that this increased flexibility may come at a cost that exceeds the benefits.

The societal desirability of fuel diversity is obviously location specific, requiring detailed analysis to be carried out on a utility-by-utility or regional electric power system basis. For example, wind resources would be expected to play a minor role in regions where wind capability is small and coal resources are cheap. An assessment of the net benefits derived from fuel diversity needs to account for the fact that some of the objectives of fuel diversity are conflicting. As an illustration, the development of integrated gasification combined-cycle (IGCC) facilities may reduce price risk and produce certain long-term environmental benefits, but likely at the cost of higher short-term electricity prices and some technology risks.[23] Generally, it would be expected that in minimizing price risk by managing a more fuel-diverse portfolio, higher electricity prices would transpire over some time frame.[24] Other objectives may be conflicting as well, complicating the efforts of policymakers and electric power suppliers[25] to design and implement the "best" plans comprised of a specific fuel-mix and different generation technologies.

Fuel diversity yields the benefit of flexibility.

Distinguishing between Short- and Long-Term Decisions

A distinction should be made between fuel diversity from a short- and long-term perspective. In the short term, a utility is limited to selecting power sources from its existing portfolio of generating facilities and third-party power purchases. Some of its power plants may have dual-fuel burners where, for example, if the price of natural gas increases or if wholesale gas supplies are deficient, the utility could switch to oil in the short run. In the long term, which is the focus of this briefing paper, the utility would contemplate what fuels it would burn in new power plants or what fuels are contained in future power purchases.[26] These fuels would be used to meet growing electricity demand in addition to displacing power from retired plants. We associate long-term decisions with what is commonly called "resource

The appropriateness of fuel diversity is specific to location.

planning." For a utility that has divested its generation capacity, long-term decisions would involve the procurement of power from various sources and under different terms and conditions.

Private parties may tend to ignore external benefits when doing their own planning.

Is Fuel Diversity an Externality?

Support for outside intervention in the electricity market to advance fuel diversity essentially derives from the premise that electric utilities and other retail electricity providers do not systematically take into account the benefits of fuel diversity in their planning decisions. The basic issue centers on whether fuel diversity should be perceived as having a positive external effect: that is private parties would tend to ignore some of its benefits when planning for new generating capacity. This problem appears more acute in the case where an electricity provider is unregulated and whose primary objective is to maximize profits. For a regulated, vertically integrated utility, objectives are broader as dictated by regulatory and legislative mandates. A state commission, for example, can direct a regulated utility to diversify its portfolio of energy resources in some limited way. Unregulated generators or retailers, in contrast, would only embrace fuel diversity if it is expected to lead to higher profits, reduced risks for their own businesses, or if wholesale/retail purchasers demand it.

Some economists might argue that fuel diversity per se is not a positive externality, thus calling into question any government policies based on the categorical objective of increasing fuel diversity as inevitably a socially desirable outcome. On the other hand, and more consistent with current thinking, to the extent that more fuel diversity is able to produce certain benefits that might not be internalized by a private generator, some form of government intervention may be warranted. For example, if a utility discounts reductions in price risk because of the extant ratemaking treatment of fuel costs, it may be prone to understating the benefits of electricity generated from renewable-energy sources that have more stable prices. Other benefits from fuel diversification such as reduced dependence on foreign sources of energy might also justify some form of interventionist policy that would shift fuel use toward domestic fuel sources. As another illustration, the learning-by-doing benefits from immature generation technologies may not be internalized by individual power providers.[27] Other situations might exist where, because of the external nature of benefits from increased fuel diversity, the market may devote too little resources to those fuel sources and generation technologies that would actualize increased fuel diversity.

Arguably, then, the societal benefits of increased fuel diversity are not being fully exploited by utilities and other electric generators. The social justification for additional fuel diversity fundamentally hinges on the magnitude of the external benefits (defined above) relative to the costs of achieving them. While most industry observers have repeated the cry for more fuel diversity with some even advocating aggressive government policies to promote it, a close examination of the net benefits may point to a more ambiguous outcome.

Application of Portfolio Theory to Fuel Diversification

The rationale for fuel diversity closely parallels the motive behind financial diversification. In the financial community, portfolio management is commonly used to manage risk and produce higher returns over time. Portfolio theory[28] teaches us that the risk of a portfolio, whether of financial assets or real assets such as electric power sources,[29] depends on three factors: (1) the risks of individual assets or electric power sources, (2) the shares of individual assets or electric power sources in the portfolio and (3) the covariances (or correlations) between the different assets or electric power sources.[30]

How Portfolio Theory Helps Decision Making

In the context of electricity, portfolio theory says that electric power sources should not be selected only for characteristics that are unique to an individual power source; rather, the utility resource planner should account for how each electric power source co-moves, in terms of price and other attributes, with all other electric power sources. In addition, taking these co-movements into account makes it possible to design and implement a portfolio that has the same expected value and less risk than a portfolio constructed by ignoring the interaction between different electric power sources. For example, a portfolio of natural gas and renewables may be preferred to a portfolio of natural gas and oil just because of the hedging benefits from renewables when natural gas prices rise.[31]

Portfolio theory, which can be viewed as the paradigm underlying the concept of fuel diversification,[32] also allows the decision-maker to conceptualize, if not quantify, the trade-off between risk and "return."[33] Defining return in terms of expected costs, one portfolio may have a lower expected cost than another portfolio with more diversified power sources, but it also may have higher risk (for example, the portfolio may be more susceptible to higher price volatility). Which of the two portfolios would be preferred requires knowing the risk preference of the decision-maker.[34] A more risk-averse decision would tend to result in a portfolio with higher expected cost but lower risk.

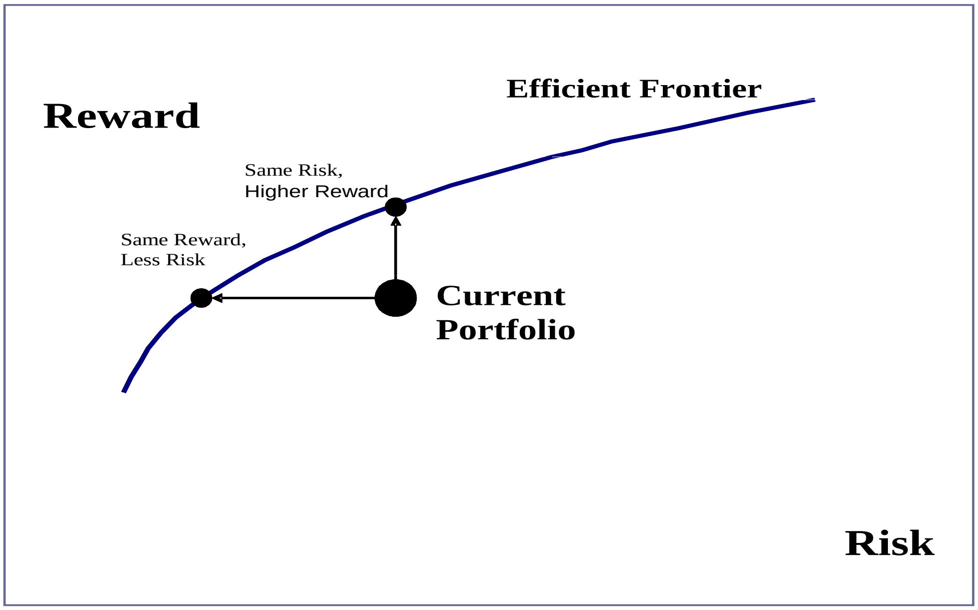
Conceivably, a more diversified portfolio could achieve both lower expected costs over time and lower risk, especially if the existing portfolio is highly inefficient. For example, an electric utility may be excessively restricting its choice-set of resources or using faulty information and analytical tools in its decision-making. As Figure 2 shows, if a utility lies within its efficient frontier, by definition it can at the same time achieve both a higher reward -- for example, lower expected cost -- and lower risk; the efficient frontier maps out the risk-reward combinations where for a given level of risk, rewards are maximized, or, equivalently, for a given level of rewards, risk is minimized. But, probably in many if not most situations, in achieving more fuel diversity a utility would have to incur higher expected costs in reducing price risk. (This rule would not hold if a utility's existing portfolio of fuels and generation technologies are highly inefficient, that is, in the context of Figure 2, lies far inside the efficient frontier.)

The rationale for fuel diversity parallels that for financial diversity.

Insights from Portfolio Theory

Several insights derived from portfolio theory are transferable to the concept of fuel diversity:

- In a diversified portfolio, resources having costs that move together may be more important than the actual variability of those individual resources – for example, the high price volatility for natural gas is more innocuous when gas prices do not move up and down together with the prices of the other fuels that are available to a utility generator.[35]



Source: Author's construct.

Fig. 2. Efficient frontier

Insights from portfolio theory aid analysis of fuel diversity.

- A utility should take particular care about those common variations in prices or supply risk (namely, what is commonly called "systematic risk," which is mainly attributable to macroeconomic conditions and, by definition, cannot be diversified away); fuel-specific risks can be reduced through diversification.

- Diversification reduces risk (as in the old adage "don't put all your eggs in one basket") – the risk level of a portfolio (measured by its standard deviation of cost) is always less than the average risk level (standard deviation) of the individual resources in the portfolio.

- Ideally, a utility should hold portfolios of generating capacity or purchased power supplies on the efficient frontier or as near to it as possible[36] – by definition, these portfolios maximize expected "return" for a given level of risk, or minimize risk for a given "return."

- Minimizing or reducing risk would as a general rule come at the sacrifice of higher expected costs in the short or long term, but *not* necessarily (as noted above).

- With diversification, and assuming the portfolio is made up of resources that vary independently or in opposite directions (i.e., zero or negative covariances between resource costs), the risk level (measured by the standard deviation of the expected cost of the portfolio as a whole) is less than the average risk level of the individual resources (i.e., the weighted average of the standard deviations of the prices of the individual resources in the portfolio). What this means is that if a utility has two different resources whose prices move in opposite directions, the collective risk of the portfolio would be less than the sum of the risks of the different resources weighted by their shares in the portfolio.[37]

- Portfolio theory, in addition to providing the underlying rationale for fuel diversity, also demonstrates the benefits of including financial hedges and other kinds of physical hedges, such as bilateral power purchase contracting and the staggering of contracts over time, in a resource portfolio.

- An ideal portfolio would include fuel sources whose prices are not correlated and, in fact, move in opposite directions to nullify each other's volatility by creating a hedge against volatile and uncertain fuel prices.[38]

- A diversified portfolio implies that decision-makers take into account factors other than the minimization of expected levelized cost or some other traditional metric.

- It is important how diversification is carried out – for example, a portfolio consisting of resources with low covariances would be preferable to others.

- The desired mix of resources in a portfolio may vary over time, as updated information about the individual resources becomes available (for example, less natural gas use could be justified as gas prices become more volatile over time).

Real Options Theory

An ideal portfolio includes fuel sources whose prices are not correlated.

Another concept, called "real options theory," can be applied to supplement the information provided by portfolio theory.[39] In its simplest terms, real options theory, which like portfolio theory provides insights for financial markets, says that when the future is uncertain, it pays to have a broad range of options available and to maintain the flexibility to exercise those options. Real options analysis represents an innovative capital budgeting approach that requires active strategic actions to maximize the value of different assets in an uncertain environment. These value-increasing opportunities to adapt to changing circumstances as uncertainty is resolved are known as *real options*. As shown in numerous studies, real options can add significant value to assets such as mines, manufacturing facilities, information systems and generating facilities.[40] Real options theory places explicit value on the ability of decision-makers to be flexible and to learn.

Real options theory can supplement the information from portfolio theory.

As with financial options, in the context of the electric industry real options would provide a utility with the opportunity but not the obligation to produce electricity from certain power plants, or procure electricity from third parties, when conditions are ripe. It is important to distinguish between opportunity and obligation, as the role of real options is to give the utility the flexibility to operate specific power plants when favorable conditions prevail. As an example, when fossil fuel prices rise unexpectedly, the utility may dispatch renewable energy to satisfy short-term demand.[41] The concept can also apply to whether a utility should build a new power plant or purchase power. In a real-world example, in the 1990s TVA decided to contract for large amounts of power rather than build a large base-load power plant. TVA's contracts

Real options theory is an innovative capital budgeting approach and maximizes the value of different assets in an uncertain environment.

allow for the option to purchase power but not the obligation. TVA ultimately ended up not exercising all of its options, which meant they paid for some without actually taking the power. The rationale for purchasing options was to provide insurance against unexpected demand, and TVA felt (by all accounts, the decision was correct in hindsight) that it was cheaper to buy options than to build a new power plant.[42]

Real options theory has also been applied to analyze the economics of renewable energy, distributed generation and coal-fired generating facilities. For example, one study calculated the benefits from continuing to leave open the option of developing coal facilities with improved thermal efficiencies and environmental characteristics; it showed these benefits to be potentially significant, resulting from lower electricity prices, increased reliability and the lowering of air pollutants.[43] The study concluded that these potential future benefits would be lost if coal were backed out of the generation mix. Another study argued that distributed generation can cause a utility to defer the upgrading of generation, transmission and distribution facilities. A decision to defer would maintain the utility's flexibility, thereby possibly avoiding unnecessary or inefficient upgrades as uncertainties become more resolved.[44] Finally, a study applied real options theory to show that renewable energy technologies are more attractive when accounting for their insurance value and their optimal-timing value,[45] in the face of uncertain future fossil-fuel prices.

Real options theory can help decision-makers adapt more quickly and cheaply to future market conditions than other available planning tools.

How Real Options Analysis Informs Construction Decisions

The major value of real-options analysis is closely linked to the benefits of having more flexibility. For example, building a production system so that it can change easily from one input to another or from one product to another, as market conditions change, is equivalent to creating "real options." In the electric industry, a dual-fuel burner that can use either oil or gas allows operators of power plants the "option right" to switch between fuels whenever it is economical to do so.

Assume that a utility has the choice of building a single-fuel natural gas plant or a plant with dual-fuel burners capable of using either natural gas (as the primary fuel) or distillate oil (as the backup fuel). The single-fuel plant is cheaper to construct and, according to discounted present value analysis, may be considered more economical on a levelized cost basis. But while the dual-fuel plant would have higher construction costs, it allows the generator more flexibility in terms of selecting the lowest-cost fuel under different market conditions.

Real options theory could also rationalize embarking upon a power-plant project that is not expected to be economical for a period of years but offers the possibility of benefits in the longer term. Some forms of renewable energy and immature generation technologies such as IGCCs come to mind as promising sources of electricity that would not be economical if operating today or even in the near future. Developing clean coal technologies today, however, can be perceived as reducing the risk of a utility in the event stricter environmental rules will be enacted in the future. Thus, additional funding of developmental activities at the present time can deliver additional options that can be exercised later if warranted by events.

Real options theory could also justify staggering the timing of capital expenditures for new generation facilities under uncertainty, committing to new construction in stages. By waiting for new information, and in the meantime initiating development of promising technologies (for example, on a pilot or demonstration basis), the utility would have more flexibility in adapting to new conditions as they unfold. The essence of real-options value derives from maintaining flexibility under uncertainty -- that is, the ability of decision-makers to adapt more quickly, and at a lower cost, to future changes in the market and in the external environment overall. In sum, the theory supports a utility, whether vertically integrated or not, creating a number of possibilities for itself.

Advantages of Real Options Theory over Conventional Planning Tools

Analytical planning tools currently heavily relied upon to evaluate resource plans, namely, net present value (NPV) or discounted cash flow (DCF) procedures, may understate the benefits from certain generation technologies that could advance fuel-diversity objectives. Real options theory has pointed to the shortcomings of the NPV/DCF rule for imputing a value on the ability of a utility to dynamically react to changing market and other conditions.[46] Specifically, this rule can understate, if not ignore, the value of managerial flexibility. In other words, it may fail to capture some of the key aspects of planning under an uncertain environment.[47] Some analysts have argued that for these reasons NPV/DCF methods for evaluating different generation technologies have biased planning decisions. Specifically, they have the tendency to reject those technologies that, although not having the lowest expected levelized costs, may have other benefits that are inadequately accounted for, or ignored, in the evaluation process. One such technology could be renewable energy. Immature technologies may also be rejected when applying the long-held traditional NPV/DCF approach because the potential benefits they offer get neglected or are understated. These benefits can include a more flexible utility system to manage unexpected events such as stricter environmental regulations regarding mercury and carbon dioxide. Renewable and IGCC technologies have the potential to provide this benefit.

Implications of Real Options Theory

The implications of real options theory for resource planning can be summarized as follows:

- Risk reduction can result from breaking large investments into series of smaller decisions; that is, spreading investments over time allows resource planners to respond to unfolding contingencies.[48]

- By investing in flexibility, utilities can take advantage of upside outcomes and avoid downside outcomes (the analogy with financial options).

- The value of system flexibility can be explicitly assessed, if not quantified; this value corresponds to the benefit of more easily, and at lower cost, “shifting gears” as future market, technological and government/regulatory conditions unfold.

- Greater value should be attached to development activities that have potential future benefits, even though their short-term benefits may be small or even negative.

Support for fuel diversity comes from all circles, with motivation that includes self-interest.

- Uncertainty offers resource planners valuable opportunities that can be exploited with use of the correct analytical methods.

- Uncertainty and volatility increase the option value of deferring and staging investments.[49] The lost option value from investing immediately in a particular technology on a large scale constitutes a legitimate economic cost. As a general principle, option value increases with higher uncertainty over the future and a longer time horizon for new investments.

- An aggressive stance toward risk involves managing the risk proactively through the use of real options (for example, by strategically developing certain immature generation technologies at varying rates over time in response to new information).

- The flexibility offered by different resource plans should be explicitly accounted for, and imputed a value if possible, in the planning process.

SUMMARY OF MAJOR POINTS AND POLICY IMPLICATIONS

The above exposition reviews key issues pertaining to fuel diversity in electric generation. The major points and implications are summarized below. It is hoped that the discussion in this paper will provide insights that policymakers and others find useful in contemplating the complex issues surrounding fuel diversity.

Support for Fuel Diversity

1. *The acceptance of fuel diversity across a wide-ranging spectrum of stakeholders and policymakers reflects recent high and volatile natural gas prices.* Up until the last few years, champions of fuel diversity were confined mainly to environmentalists and advocates of renewable energy. As noted above, the current sweeping support for fuel diversity has come from all circles for various reasons, including self-interest, and is expected to continue in the future. Natural gas has lost some of its appeal and will continue to be held suspect as a fuel for electric generation as long as gas markets remain tight. A major concern is that heavy reliance on natural gas for new generating capacity can expose electricity consumers to severe price volatility; excessive reliance on natural gas for power generation also increases prices and limits supplies available to other natural gas consumers, for example industries that heavily use natural gas as a feedstock as well as residential customers relying on natural gas for home heating. There seems to be a consensus among industry observers that it is imperative as a nation to find alternatives to natural gas as a source of fuel for new generating facilities, especially if natural gas supplies continue to be tight in the foreseeable future.

   Notwithstanding the strong support for fuel diversity, forecasts call for the continued dominance of fossil fuels in electric generation beyond the next 20 years, notwithstanding the problems that this category of fuel source apparently poses for policymakers and planners. While this may not necessarily be undesirable, it does raise the question of whether non-fossil fuels are being given due consideration as possible future energy sources for electric generation.

2. *Policymakers and interest groups have idiosyncratic visions of the ideal fuel-diversity future – for example, the optimal mix of fossil-fuel, renewable energy, and nuclear power in a utility or regional electric power system.* Some advocates of fuel diversity are really arguing that certain fuels because of their singular features should be given serious consideration as incremental sources of future electricity supply. If, in fact, these energy sources are developed and commercialized to the levels hoped for by their advocates, fuel diversity, in its generic meaning, may actually regress. For example, the development of IGCCs may displace other technologies that would have the ability to narrow the market-share gap across fuel sources for an individual electric utility or regional electric power system. Of course, this may not be problematic if IGCCs in fact lower electricity costs or lessen some risks, or both, in the long term.

3. *Electric utilities, whether vertically integrated or not, are beginning to place more importance on fuel diversity in reducing risks.* But the tough challenge for them will be to identify those generation technologies that best fit into their portfolio of electric power sources, after accounting for the risks of individual technologies and their covariances with each other.

4. *In this time of great uncertainty over future market conditions, environmental regulations, and government/regulatory actions, all generating-technology options should be seriously considered.* Most industry analysts seem to concur with this. The challenge is to apply theoretically sound, time-tested approaches to measuring the full value of the individual technologies in the context of an individual or regional electric power system.

Reasons for Current Situation

5. *Historically, utilities and non-utilities tended to select the least-cost generation technologies without full consideration of their different risks.* This practice has been transformed somewhat in recent decades to where planners have given more attention to the risk of individual generation technologies. The surge in natural gas-fired generation capacity since the early 1990s illustrates this, but, paradoxically, it is because of post-2000 tightening of natural gas supply, leading to higher price volatility, that the market and policymakers have

Financial incentives may be warranted to promote innovative but promising high-risk technologies.

recently questioned the reliance on atural gas as a dominant fuel source for new generation capacity.

6. *The question of why there is not more fuel diversity in the electric industry has no definite answer.* Failures, originating from distorted market incentives or flawed government actions, offer a partial explanation. The current fuel mix for electric generation probably reflects pretty closely a rational response by utility and non-utility decision-makers to prevailing market, technological and regulatory conditions. Suitable public policies hinge on the reasons for why the benefits from fuel diversity are not being fully exploited, if in fact that is the case.

Need for Good and Innovative Analysis

7. *The meaning of fuel diversity and how it can best advance certain social objectives call for thoughtful analysis.* Achieving an optimal or preferred fuel diversity goes beyond mere economic considerations to include environmental, national security, and electric-power-system reliability effects; that is, social goals that have positive and negative externalities. As emphasized above, fuel diversity is best viewed as a means to achieving specified objectives – not an end in and of itself. The policy implication of this perception is that subsidies or financial incentives designed solely to buttress certain generation technologies in the name of fuel diversity should be rejected in the absence of sound information on the expected benefits. Multi-objective planning and power acquisition, rather than fuel diversity per se, should be the real motive for evaluating and commercializing various generation technologies and their fuel sources.

8. *The high degree of uncertainty over the future warrants serious consideration of a diversified portfolio approach by retail electric utilities.*[50] This approach explicitly takes into account the risks of different resource options, on both a stand-alone and system-wide basis.

9. *All generating technologies have their shortcomings and challenges, as well as attractive features, but all or most of them may be accommodated within a diversified generation/procurement portfolio framework.* The task for resource planners is to blend these technologies in their electric power systems so as to produce an efficient outcome in terms of achieving the "optimal" trade-offs between conflicting planning objectives.

10. *Resource planners should consider the risks associated with individual technologies in terms of their overall risk effect on a utility system or regional electric power system.* This is a tenet of portfolio theory that may not always be practiced because of faulty planning analysis in addition to other reasons. Some technologies that seem inherently risky may fit nicely in the context of the entire portfolio, especially if their costs have a low correlation with other technologies. Renewable energy comes to mind as such a technology.

11. *Planners and decision-makers will likely wish to focus more on quantifying the risks of individual generation technologies, as well as the benefits of flexibility, and less on discounted cash flow (DCF) or*

net present value (NPV) economics where risk and option value may be given inadequate consideration. For example, these analytical tools may underestimate the full value of renewable energy in lessening the impact of price increases and the volatility of fossil fuels. This insurance-type benefit could result from renewable energy playing the role of a "backstop" technology in times of price spikes for fossil fuels. The traditional tools also seem to inadequately impute a value on developmental and other activities that would allow electric power system operators more flexibility as future market, environmental and government/regulatory events unfold.

12. *Real options theory can help to conceptualize, in addition to measuring,*[51] *the value placed on individual new generation technologies.* Some of these technologies – good examples are renewable-energy technologies, nuclear power and IGCCs – may currently have higher levelized costs than other technologies, but hold the promise of being economical and socially desirable under specific future states of the world. These states may include the continuation of tight oil and natural gas markets, and strict regulation of carbon dioxide emissions. Real-options analysis would account for the ability of a utility to react to new circumstances. The utility can do this by spending incrementally on certain technologies initially, acquiring new information, then making the decision to either proceed ahead at full speed or slow down or suspend development of the technology.[52] The real options approach explicitly takes into account the value of managerial flexibility and the strategic value of different generation technologies. In ignoring or slighting these benefits, certain technologies may be wrongly rejected.

13. *The value of fuel diversity to consumers comes down to their willingness to tolerate risk.* As noted above, one of the potential benefits of fuel diversity is to reduce the price volatility of electricity. If consumers place a high value on price stability, as some studies have shown, then this benefit of fuel diversity becomes important.

Policy Issues

Fuel diversity is a means, not an end.

14. *Financial incentives, such as loan guarantees and tax credits, may be justified in promoting promising, immature, high-risk technologies.*[53] If so, they should be explicitly linked to the social value of the benefits that are not recognized in the marketplace.[54] These benefits can include the learning-by-doing phenomenon, a cleaner environment, less dependency on foreign sources of energy and price-risk reductions.[55] Arguably, some of these benefits may already be internalized by market participants, for example, through some form of hedging to manage price risk, and others may be insignificant (for example, oil imports since little of this energy source is currently used for electric generation).

15. *State commissions may want to consider whether they would benefit from granting upfront approval for new, immature but promising generating technologies, assuming they have authority over these facilities.* Given the inherent risks with these technologies, regulatory

The external nature of some benefits that could be realized with more fuel diversity may require government actions.

preapproval of their development may be critical from a utility's perspective in balancing the risk/ reward relationship at a tolerable level. Otherwise, the utility may perceive these technologies as too risky to develop. Upfront regulatory approval may also be generally required before a utility would develop and put in place a portfolio approach for utility resource planning and acquisition. On the downside, full regulatory commitment up-front can create a serious "moral hazard" problem that could provide a utility with bad incentives to keep costs down in developing and commercializing pre-approved, and oftentimes complex, technologies.

CONCLUSION

Fuel diversity for electric generation has gained prominence in the aftermath of high natural gas prices of the past few years. This unprecedented interest reflects a problem that in recent history has plagued the electric industry – namely, the over-reliance on a single generation technology over a number of years as the primary source of new capacity. In light of a highly uncertain future, the United States is now at the crossroads where it would be ill-advised to write off any generation technology that offers some promise in meeting future social objectives, whether they are economic, environmental or otherwise in origin.

In evaluating the different generation technologies, traditional analytical tools may need to be revamped so that the societal benefits from fuel diversity are sufficiently taken into account. Traditional tools such as net present value or discounted cash flow analysis may lead to incomplete and distorted information on the economic effect of different generation technologies. For example, these tools may fail to include those real benefits external to a utility or unregulated generator. Relying on these tools in the future could bias planning decisions away from those technologies with promising longer-run societal benefits. Quantifying the risks associated with different generation technologies underlies the analytical challenge for resource planners.

The external nature of some benefits that could be realized with more fuel diversity may require government actions. Especially for unregulated wholesale generators, these benefits may be unaccounted for in making planning decisions. Care must be taken to avoid policies that would make matters worse, as the benefits from more fuel diversity may come at a too high cost.

Finally, as a major point in this paper, fuel diversity per se should not be viewed as an aspiration. Its sole value lies with advancing certain social objectives that are deemed to be important but oftentimes conflicting. When not done intelligently, achieving higher fuel diversity can easily afflict higher costs on society. Fuel diversity is only one of alternative means to achieving an optimal balancing of social goals within the context of an individual or regional electric power system.

Notes

[1] We can expect that as traditional energy supplies become increasingly scarce and their prices rise, renewable resources and other nontraditional sources will become more commercially viable. This outcome succinctly depicts the market-driven dynamics in responding to higher fossil fuel prices.
[2] Edison Electric Institute Board of Directors, "Framework for the Continuing Development of a Competitive Wholesale Market for the Benefit of Consumers," Jan. 7, 2005.
[3] E. Linn Draper Jr., "Life After Y2K: Not Your Father's Electricity Business," *The Electricity Journal* 12, Issue 10 (December 1999), 26. In the article, Draper also commented that "In considering fuel diversity for the future it is important to recognize that each source of power generation…has its own problems and limitations."
[4] For example, in November 2003 NARUC passed a resolution encouraging State commissions to consider portfolio management methods for resource planning by electric utilities. NARUC's interest in fuel diversification includes power procurement for both integrated utilities and default service procurement in retail choice states.
[5] The National Regulatory Research Institute, *The State of Regulation: A Preview of Key Issues Facing Commissions in 2005*, proceedings of the Commissioners-Only Summit, New Orleans, Louisiana, January 16-18, 2005, February 2005, 13-15.
[6] These states include Arizona, California, Colorado, Connecticut, Florida, Hawaii, Iowa, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New Mexico, New York, Pennsylvania, Rhode Island, Texas and Wisconsin. (See Ryan Wiser et al., *Evaluating Experience with Renewables Portfolio Standards in the United States*, LBNL-54439, March 2004.)
[7] While energy-efficiency options can be included in portfolio analysis, this paper excludes explicit discussion of this alternative as it focuses on different generation technologies and their fuel sources.
[8] Currently, about 70 percent of the electricity produced in the United States comes from fossil-fuel generating facilities.
[9] See historical issues of the U.S. Energy Information Administration, *Electric Power Annual*. The latest issue, at the time of this writing, was published in December 2004.
[10] Over the period 1978-1984, for example, oil-fired generation plummeted by over 68 percent. Reasons for this included the second OPEC price shock, starting in late 1978, and the enactment of new federal legislation that discouraged oil consumption (for example, the Power Plant and Industrial Fuel Use Act of 1978).
[11] An astonishing statistic is that until 1998 over 90 percent of the nation's wind, solar, and geothermal energy development occurred in a single state, namely, California. (See Ryan Wiser et al., "Emerging Markets for Renewable Energy: The Role of State Policies during Restructuring," *The Electricity Journal* 13, Issue 1 (January/February 2000), 20.)
[12] As another example, in Florida the share of natural gas in electric generation increased from about 13 percent in 1993 to 32 percent in 2004, with projections of over 50 percent by 2013.
[13] Energy Information Administration, *The Annual Energy Outlook 2005, Early Release (AEO2005)*, December 2004. Specifically, EIA projects for 2025 the following shares of individual fuels in the generation of electricity: 50 percent (coal), 14 percent (nuclear), 24 percent (natural gas), 8 percent (renewables, including hydropower), and 3 percent (oil).
[14] The modular feature would be particularly beneficial in a competitive environment where electricity price uncertainties are evident.
[15] Tight conditions are anticipated over the next few years, with continued high and volatile natural gas prices persisting. See, for example, National Petroleum Council, *Balancing Natural Gas Policy – Fueling the Demands of a Growing Economy*, Volume I: Summary of Findings and Recommendations, September 2003.
[16] See John Stewart, "Resource Decision Making," Joint Meeting of the Committee on Energy Resources and the Environment, and the Committee on Electricity, July 2004; Bill Edmonds, "Planning in the Dark: Accounting for Gas and Carbon Risk," Conference on The Natural Gas Crisis: Finding Clean Solutions, Jan. 25, 2005; and PacifiCorp, *2004 Integrated Resource Plan*, Jan. 20, 2005.
[17] See Wayne Brunetti, Chairman and Chief Executive Officer, Xcel Energy, "Powering Colorado: A New Balancing Act," presentation before the National Western Mining Conference, February 5, 2004. Brunetti remarked that "A diverse fuel portfolio enables us [Xcel Energy] to better manage fuel risk and keep customer prices as low as possible. Fuel diversity also lets us take full advantage of the benefits each fuel brings to our portfolio."

[18] On Dec. 3, 2004, Xcel Energy filed with the Colorado Public Utilities Commission a settlement agreement regarding its plan. The plan, which has been endorsed by several intervening parties, was approved by the commission later in the month. The 10-year plan calls for Xcel Energy to build a 750 Mw coal-fired plant, to spend up to $196 million on energy efficiency, and to solicit bids for wind power up to 15 percent penetration on its electric power system.

[19] These include electric utilities in California, Montana, Nevada, New Jersey and Oregon. In California, for example, utilities are to "incorporate various instruments into the energy system planning process … to enable [the California PUC] to achieve our policy goals of sustainable, reliable and reasonably priced energy service in ways that limit the environmental consequences of the supply process." (California Public Utilities Commission, Decision 04-01-050, Jan. 22, 2004) (See Johannes Pfeifenberger et al., "Keeping Up with Retail Access? Developments in U.S. Restructuring and Resource Procurement for Regulated Retail Service," *The Electricity Journal* 17, Issue 10 (December 2004): 50-64.) The article describes the portfolio approach as one in which "the utility retains the day-to-day responsibility for directly procuring resources, managing price and volume risks, and providing full-requirements, load-following service for its regulated service customers. This would generally be done according to Commission-approved processes." A comprehensive overview and analysis of the application of portfolio theory for electric utilities is contained in Bruce Biewald et al., *Portfolio Management: How to Procure Electricity Resources to Provide Reliable, Low-Cost, and Efficient Electricity Services to All Retail Customers*, Oct. 10, 2003. (see http://www.synapse-energy.com/Downloads/Synapse-report-rap-ef-portfolio-management-10-10-2003.pdf)

[20] Financial hedges, however, may be best viewed as a short-term tool to deal with price risk.

[21] See, for example, Frank C. Graves et al., *Resource Planning and Procurement in Evolving Electricity Markets*, prepared for the Edison Electric Institute, Jan. 31, 2004, 21.

[22] Optionality refers to the increased choices that a utility has in efficiently and quickly responding to new information and unexpected market and policy events. Some of these options may never get exercised, but their availability allows the utility to maintain flexibility in the face of uncertainty (see discussion below on real options theory).

[23] IGCC facilities currently have higher capital, operating and financing costs than conventional coal-fired generating units. They would have lower air pollutant emission rates than traditional coal facilities and some other fossil fuel facilities, but may have greater greenhouse gas emissions than oil and natural gas facilities. It is expected that the commercialization of immature technologies, such as IGCC facilities, at least in their early years will entail operating and cost uncertainty and require financial assistance from electricity consumers in addition to possible subsidies from taxpayers. Finally, it is expected that because IGCC facilities will be built in coal supply regions they will not contribute to higher fuel diversity.

[24] Proponents of IGCCs may argue that this technology could lower electricity prices in the long run, as less natural gas would be used for electric generation.

[25] Electric power suppliers can include traditional vertically integrated utilities, single plant owners, and energy service providers who may self-generate or purchase power in the wholesale market and resell it directly to retail consumers or distribution utilities.

[26] For a utility that has divested its generation facilities, fuel diversification still becomes relevant for State commissions and the utility in the context of the development and management of a power procurement portfolio.

[27] Learning-by-doing is a concept that refers to the phenomenon of production and capital costs declining, with less mistakes being made, as more experience with a technology accumulates over time. Because first movers may not capture all of the benefits from this experience, some going to rivals, this "spillover" effect would tend to underallocate resources to research and development as well as commercialization endeavors. This effect provides a rationale for government-funded financial incentives. Incidentally, although not accounting for learning-by-doing benefits would hamper the development of these technologies, it may not always be the case that this would run counter to achieving more fuel diversity. Taking the case of IGCC technologies, promoting their deployment and commercialization would lead to less fuel diversity, since coal is currently the dominant fuel source for electric generation and IGCC technologies would displace generation technologies using other fuel sources.

[28] The origins of modern portfolio theory can be traced to Harry Markowitz, who received a Nobel Prize in economics largely because of his work in portfolio theory. (See Harry Markowitz, "Portfolio Theory," *The Journal of Finance* 7 (March 1952): 77-91.)

[29] Electric power sources can include self-generated electricity and power purchases from third parties.

[30] As an example, natural gas and oil prices are highly correlated, while the prices of renewables and fossil fuels (natural gas, oil and coal) have much lower correlation. An application of portfolio theory to the U.S. electric sector

is contained in H. Brett Humphreys and Katherine T. McClain, "Reducing the Impacts of Energy Price Volatility through Dynamic Portfolio Selection," *The Energy Journal* 19, Issue 3 (July 1998): 107-131. The article emphasizes that an efficient portfolio, which explicitly takes into account the impact of price shock, may not produce a least-cost outcome.

[31] It is assumed here that movements in natural gas and oil prices are highly correlated, which is consistent with historical price behavior.

[32] The word "diversification" connotes having available electric power sources that have dissimilar qualities. One such quality may be a low correlation of price movements across different fuel sources.

[33] Mathematically, the expected "return" for a portfolio with i electric power sources is equal to:
$E(R_p) = \Sigma\ w_i E(R_i)$, where $E(R_i)$ is the expected "return" from electric power source i and w_i is the weight of electric power source i held in portfolio p. The risk of the portfolio is equal to its variance: $\sigma^2_p = \Sigma\ \Sigma\ w_i w_j cov(i,j)$, where cov(i,j) is the covariance between two electric power sources i and j.

[34] Risk preference, for example, refers to the extent to which retail electricity consumers place a value on being insulated from price variance. This value is more difficult to measure than the cost of achieving a more diverse generation mix (i.e., the cost of deviating from a least-cost strategy).

[35] Fossil fuels tend to move together because of their substitutability.

[36] Of course, because of the probabilistic nature of the parameters required to map out a frontier function, the efficient frontier cannot be known with certainty.

[37] See footnote 33 for a mathematical demonstration of this.

[38] Such a portfolio may be difficult to construct since fuel prices, especially for fossil fuels, tend to move together. This is unlike the case of stocks where there are numerous stocks from which to choose whose prices tend to move in opposite directions.

[39] An excellent discussion of real options theory is contained in Avinash K. Dixit and Robert S. Pindyck, *Investment Under Uncertainty* (Princeton, NJ: Princeton University Press, 1994); and Robert S. Pindyck, "Irreversible Investment, Capacity Choice, and the Value of the Firm," *The American Economic Review* 78, no.5 (December 1988): 969-985. The origins of real options theory can be traced back to the work of Myron Scholes, Robert Merton and Fischer Black in the early 1970s. This work developed a theoretical framework for pricing financial options.

[40] See, for example, Lenos Trigeorgis, *Real Options: Managerial Flexibility and Strategy in Resource Allocation* (Cambridge, MA: The MIT Press, 1996); *The Quarterly Review of Economics and Finance*, 38, Special Issue, 1998; Jens Bengtsson, "Manufacturing Flexibility and Real Options: A Review," *International Journal of Production Economics* 74 (2001): 213-224; Dhiman Chatterjee and VC Ramesh, "Real Options for Risk Management in Information Technology Projects," *Proceedings of the 32nd Hawaii International Conference on System Sciences*, 1999; and Julia Frayer and Nazli Z. Uludere, "What Is It Worth? Application of Real Options Theory in the Valuation of Generation Assets," *The Electricity Journal* 14, Issue 8 (October 2001): 40-51.

[41] In this illustration, the net value of this real option should account for the capital cost associated with the renewable-energy facility. After performing this calculation, it may not be economical to have the renewable-energy facility on standby and available for dispatch when needed. In general, real options are not economically justifiable when their value falls short of costs.

[42] An illustration of a failure to retain an option would be where a utility signs a long-term purchased power contract with rigid take and price provisions. If subsequent to the signing of the contract the market price of electricity plummeted or expected load growth failed to materialize, or both, the utility could suffer large contractual liability.

[43] See Electric Power Research Institute and LCG Consulting, *Real Option Valuation of Coal Generation and Coal R&D in the United States*, 2001. The report "uses the modern financial technique of real options analysis to…capture the operational flexibility of the generators, optimizing dispatch, and thereby maximizing their net incomes and the strategic adaptability inherent in R&D investments."

[44] Distributed generation can also enhance power system flexibility and reliability, with the latter the result of depending less on bottleneck-susceptible transmission facilities.

[45] This refers to the optimal time renewable-energy facilities should be developed and ready for operation in the event, say, of an unexpected rise in fossil fuel prices. (See Graham A. Davis and Brandon Owens, "Optimizing the Level of Renewable R&D Expenditures Using Real Options Analysis," *Energy Policy* 31 (2003):1589-1608.)

[46] As succinctly articulated by a well-known expert of real options theory, when an investment is largely irreversible, uncertainty exists over cash flows, and investments could be delayed, "the use of the simple NPV rule is incorrect

because it does not maximize the firm's value, i.e., the firm would do better making investments under different assumptions than those used in the NPV rule." (See Robert S. Pindyck, *Declaration of Robert Pindyck*, before the Federal Communications Commission, WC Docket No. 03-173, 6.)

[47] Proponents of the NPV/DCF procedure would counterargue, with some validity, that this method can account for risk and option value by adjusting the basic framework for these effects. This can be done by applying scenario analysis or decision tree analysis, and imputing subjective probabilities and appropriate discount rates, or by supplementing the method with some kind of stand-alone risk analysis. An advantage of real options analysis over the NPV/DCF approach, however, is that probabilities and discount rates are no longer arbitrary.

[48] See, for example, Christian Gollier et al., "Choice of Nuclear Power Investments under Price Uncertainty: Valuing Modularity," unpublished paper, February 2004. The authors analyzed two investment scenarios: (1) an irreversible investment in a large nuclear power plant, and (2) building a sequence of smaller, modular, nuclear power plants on the same site. The paper applied real options theory to measure the value of building successive modules under price uncertainty.

[49] See, for example, Jun Ishii and Jingming Yan, "Investment under Regulatory Uncertainty: U.S. Electricity Generation Since 1996" (CSEM WP 127), Center for the Study of Energy Markets, March 2004. The authors developed a theoretical model hypothesizing that, in an environment of regulatory uncertainty, the delay in investments in new power plants can partially be explained by the "option value" from deferring investment decisions and acquiring new information in future periods.

[50] As noted earlier, several retail utilities have recently taken this approach. See Johannes Pfeifenberger et al., "Keeping Up with Retail Access? Developments in U.S. Restructuring and Resource Procurement for Regulated Retail Service." (supra., 19)

[51] The valuation of real options often requires sophisticated approaches, such as numerical techniques and stochastic dynamic linear programming, as well as highly technical people to carry out.

[52] The price of real options corresponds to the initial expenditure in developing a new source of electric power, while the exercise price corresponds to the cost of the follow-up investment.

[53] Financial incentives can also be offered to assist mature generation technologies, such as those that use renewable energy, that are not currently commercially viable.

[54] This is consistent with the view that significant market and regulatory imperfections make nontraditional technologies appear unprofitable to private firms, even though the societal value of these technologies may be considerable. Of course, the social cost of subsidies should be calculated and compared with the societal benefits to determine the desirability of these subsidies.

[55] Candidate technologies for government assistance include first-of-a-kind facilities that have "public good" characteristics. The policy question then becomes: given government's limited resources, which technologies should be offered assistance?

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This report was prepared by the National Regulatory Research Institute (NRRI) with funding provided by the member commissions of the National Association of Regulatory Utility Commissioners (NARUC). The views and opinions of the authors do not necessarily express or reflect the views, opinions or policies of the NRRI, NARUC or NARUC member commissions.