*Energy Studies Review Vol. 14, No.1, 2006 pp120-135*

# Adapting for Uncertainty: A Scenario Analysis of U.S. Technology Energy Futures

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**ABSTRACT**

Policymakers and managers in the U.S. energy sector will face complex multidimensional challenges as they confront potential supply shortfalls, infrastructure constraints, and environmental limitations in the years ahead. Using a technique known as scenario analysis, this paper investigates key energy issues and decisions that could improve or reduce the ability of the United States to deal with the uncertainties that may challenge the U.S. economy during the next fifty years. Four scenarios have been developed representing a diverse range of future worlds to explore the driving forces and critical uncertainties that may shape U.S. energy markets and the economy for the next fifty years. Each scenario has been quantified using a computable general equilibrium model, the All Modular Industry Growth Assessment model, also known as the AMIGA modeling system.

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The preliminary results from the scenario analysis suggest that the range of feasible U.S. energy futures is broad, but that energy use is expected to grow under all scenarios. At the same time, the introduction of policies to encourage capital stock turnover and accelerate the commercialization of high-efficiency, low-emissions technologies can significantly reduce future primary energy demand in the United States. Not surprisingly, the analysis suggests that low energy prices can lead to higher economic growth than might occur under standard reference case assumptions. But the analysis also finds that a smart investment path, one that emphasizes both energy efficiency improvements and advanced energy supply technologies, can provide an economic growth similar to lower energy prices.

## INTRODUCTION

"Energy is closely linked to economic prosperity," began the George H.W. Bush Administration's National Energy Strategy more than a dozen years ago (U.S. Department of Energy 1991). Despite this close link, it appears that global concern for adequate and environmentally-sound energy resources have not been supported by appropriate investments in new resources and new technologies. A growing number of researchers and scholars have warned that global shortfalls in the availability of conventional energy resources could occur as early as 2030 (Abt 2002; Hoffert et al., 2002; and Metz et al., 2001).

The major concern is not that the world is running out of all energy resources, but rather that the major non-renewable supplies of oil, gas, and arable lands are being rapidly and irreversibly depleted. It is very likely a huge investment in both Research and Development (R&D) and infrastructure will be needed over the next several decades to ensure adequate energy availability and to commercialize the technologies that will replace cheap fossil fuels. Technologies likely to receive the most attention include unconventional fossil fuels, hydrogen, renewable resources, advanced nuclear power systems, and more energy-efficient machinery, equipment, and appliances. Even with the promise of these new technologies and resources, the question has not been asked: "What is the mix of resource investments that make the most sense for the United States — given the need for balanced economic growth, enhanced environmental quality, and improved international security?" These are the kind of questions that Wirth et al. (2003) try to answer, and that we attempt to explore through the use of scenario analysis (Schwartz 2003).

## 1. SCENARIOS OF FOUR FUTURE WORLDS

To fully explore the future of U.S. energy markets and their impact on the economy for the next fifty years, four scenarios have been developed representing a diverse range of future worlds. We use the AMIGA modeling system to evaluate the economic interactions and impacts of these four scenarios. AMIGA is a 200-sector computable general equilibrium model of the international economy with a detailed representation of both energy efficiency and energy supply technologies (Hanson 1999; and Hanson and Laitner 2004). These technologies include all of the ones most likely to be evaluated and promoted in the next 30 to 50 years. Described in a report released last year by the Argonne National Laboratory (Hanson et al 2004), the four scenario narratives discussed here include:

- The Official Future;
- Cheap Energy Reigns Supreme;
- Big Problems Ahead; and
- Technology Drives the Market.

Table 1, on the following page, provides key energy and economic indicators for comparison among the scenarios and to a set of linked policy cases (referred to as the "challenge and response cases"). We next describe the context or story logic that drives each of the scenarios.

### *1.1 The Official Future*

The Official Future is a reference scenario that we benchmarked to the Annual Energy Outlook 2002 (Energy Information Administration 2002). The Annual Energy Outlook (AEO) forecast reflects conventional wisdom about the future patterns of U.S. energy supply and demand through 2020. For The Official Future, we assumed that existing U.S. policies, trends in market structure, and the market shares of various technologies generally follow a similar pattern in the years 2020 to 2050. Like each of the scenarios that follow, The Official Future is not a prediction or a forecast. It simply represents an internally consistent view of the way in which U.S. energy markets could evolve over time if current policies remain unchanged for the next fifty years. The Official Future is used as a reference case for purposes of comparison with the other scenarios described below.

There are no major conflicts in The Official Future. Federal policies on energy and economic development achieve their goals. New technologies enter the market gracefully, with incumbent technologies readily adjusting to all new challenges. Foreign governments seek to cooperate with U.S. policy in the interest of stimulating global economic growth. Patterns of housing, urban development and agriculture all continue to follow recent trends.

**Table 1. Summary Indicators for Historical Year 2000 and Study Scenarios Year 2050**

| Energy or Economic Indictor | Year 2000 Historical | The Official Future | Cheap Energy Reigns | | Big Problems Ahead | | Technology Drives Market | |
|---|---|---|---|---|---|---|---|---|
| | | | Base | Policy | Base | Policy | Base | Policy |
| Gross Domestic Product (Trillion Dollars) | $9.9 | $36.9 | $39.8 | $39.3 | $32.3 | $32.0 | $39.8 | $39.7 |
| Primary Energy Demand (Quadrillion Btu's) | 100.3 | 157.5 | 165.0 | 106.3 | 124.5 | 105.6 | 127.5 | 102.2 |
| Carbon Emissions (Million Metric Tons) | 1,559 | 2,471 | 2,584 | 914 | 1,879 | 859 | 1,741 | 839 |
| Oil and Gas Imports (Billion Dollars) | $133 | $313 | $338 | $58 | $215 | $94 | $137 | $53 |
| World Oil Price (Dollars per Barrel) | $27.72 | $26.74 | $22.94 | $15.13 | $40.46 | 37.76 | $21.26 | $18.74 |
| Average Wellhead Natural Gas Price (Dollars per Thousand Cubic Feet) | $2.76 | $5.38 | $6.13 | $2.42 | $6.25 | $4.87 | $4.82 | $3.19 |
| Average Electricity Price (Dollars per Megawatt-hour) | $67 | $79 | $76 | $120 | $91 | $109 | $82 | $107 |
| Light Duty Vehicle Travel (Billions Miles per Year) | 2,400 | 4,588 | 5,436 | 3,879 | 3,738 | 3,407 | 3,990 | 3,753 |
| New Car Fuel Economy (Average Miles per Gallon) | 22.8 | 25.5 | 25.5 | 67.4 | 56.1 | 74.3 | 49.4 | 77.7 |
| Average Fossil Fuel Heat Rate (Btu's per Kilowatt-hour) | 10,730 | 7,036 | 6,894 | 7,899 | 7,565 | 9,232 | 7,546 | 8,553 |

Notes: (1) All dollar values are constant 2000 dollars; and (2) The conversion of nuclear and renewable electricity production into primary energy is based upon average fossil fuel heat rates rather than the standard conversion units assumed in other models. For more detailed results over the full 50-year time horizon of these scenarios and their respective policy cases, see Hanson et al. (2004), available going to the publications section of the AMIGA website. The URL is: http://amiga.dis.anl.gov.

U.S. energy demand increases at a slow and gradual rate of about 0.9 percent per year for the entire 50-year period. Total U.S. primary energy demand rises from approximately 100 Quads in 2000 to 157 Quads in 2050. During the same period, the U.S. economy grows at an average rate of about 2.7 percent per year, experiencing few shocks and no significant disruptions. At this annual rate of growth, U.S. Gross Domestic Product (GDP) increases from just under $10 trillion in 2000 to about $37 trillion in 2050 (measured in constant year 2000 dollars).

Improvements in the energy intensity of the economy notwithstanding, the overall effect of economic growth, and the resulting use of fossil fuels, is to increase air pollutant emissions. Emissions of local air pollutants (including oxides of sulphur and nitrogen plus particulates) grow steadily with the rising demand for energy in general and for fossil fuels in particular. Fossil-fuel related emissions of carbon dioxide ($CO_2$) increase from 1561 million metric tons of carbon equivalent (MMTC) in 2000 to 2,471 MMTC in 2050. In short, The Official Future is an optimistic, surprise-free scenario, a world of "more of the same," with no major discontinuities or disruptive technologies.

### *1.2 Cheap Energy Reigns Supreme*

Cheap Energy Reigns Supreme is a more extreme version of the world foreseen in The Official Future. This is a scenario in which abundant and inexpensive supplies of oil and gas continue to fuel the engines of economic growth in United States. American foreign policy is designed to provide continued access to low-cost supplies of oil and gas, placing great emphasis on stability in oil-producing regions. American consumers sustain their historical dependence on cheap fuels and disregard the occasional breakdown of energy supply and delivery systems. Environmental impacts of energy supply and use are considered to be the unavoidable consequences of economic growth.

As this scenario unfolds, OPEC leaders determine that their interests align closely with those of the United States and other industrialized, oil-importing countries. Thus, producers seek to maximize output while keeping prices low enough to promote sustained economic growth in developing countries. Confident of continuing increases in world oil demand, OPEC manages the world oil market so as to discourage R&D on new or alternative technologies that could lower future oil demand and, in so doing, to delay the commercialization of potentially competitive technologies.

Driven primarily by low prices, United States imports of petroleum and petroleum products grow even more rapidly in this scenario than they do in The Official Future. Total imports of petroleum and petroleum products reach almost 50 Quads in 2050, compared to 24 Quads in 2000.

Still more dramatic changes occur in the natural gas market. Gas demand triples in Cheap Energy Reigns Supreme, rising from 23 Quads in 2000 to 70 Quads in 2050. Two-thirds of the increase is achieved through expansion of domestic production, with rapid advances in exploration and production technology allowing U.S. energy companies to open up unconventional resources in tight formations, off-shore fields, unmineable coal seams, and Arctic basins. Substantial private investments in new pipeline and distribution infrastructure, begun in the 1990s and continued throughout this scenario, allow these new resources to be delivered to end-users in the Lower 48 states.

With seemingly unlimited supplies of cheap oil and gas steadily available, travel increases significantly. Fuel economy remains largely unchanged relative to The Official Future. U.S. total primary energy demand grows at an average rate of about one percent per year in Cheap Energy Reigns Supreme, reaching 165 Quads per year in 2050. Fueled by cheap energy, the U.S. economy grows at an annual average rate of approximately 2.8 percent during the same period. At this rate, the U.S. economy expands by a factor of four, from about $10 trillion in 2000 to nearly $40 trillion in 2050. In this world of cheap energy and domestic tranquility, the federal government makes no effort to promote energy efficiency or low-emissions technologies.

With increasing use of all types of fossil fuels, it is not surprising that air pollutant emissions increase in Cheap Energy Reigns Supreme. Emissions of particulates, oxides of nitrogen, and oxides of sulphur increase by hundreds of millions of tons per year. Carbon dioxide emissions from fossil fuel combustion grow from 1,559 MMTC in 2000 to an estimated 2,584 MMTC in 2050. In sum, Cheap Energy Reigns Supreme is a scenario characterized by inexpensive and seemingly limitless supplies of oil and gas. This surprise-free scenario exposes the United States to no major discontinuities or disruptive technologies.

### *1.3 Big Problems Ahead*

Big Problems Ahead is a chaotic, event-driven scenario. Domestic policy is disjointed and episodic, buffeted by forces beyond U.S. shores. Similar to Cheap Energy Reigns Supreme, principal actors in this scenario include U.S. policy-makers, U.S. business leaders as well as leaders of foreign governments. But in addition, sub-national groups also play a role.

In contrast to Cheap Energy Reigns Supreme, foreign governments do not support U.S. policy goals or cooperate with U.S. leaders in Big Problems Ahead. They envision their interests strongly in conflict with the U.S. regime and see U.S. policies as designed to promote the imperial ambitions of the United States. They have no interest in preserving a tranquil environment to support U.S. economic growth. As a consequence of these conflicting visions, many foreign actors (including terrorist groups) take steps to limit U.S. access to resources and to disrupt international trade in energy resources. Chronic instability among Gulf regimes leads to a roller-coaster ride of rapid oil price surges, stressing the U.S. energy sector. Intermittent cut-offs of oil supply from the Gulf cause discontinuities in the path of economic development for both industrialized and developing countries. Efforts to develop new energy resources in the Lower 48 also encounter unexpected setbacks. For example, the federal government's attempt to reinvigorate the 1980's era synfuels program fails.

Reeling in another direction, the federal government decides to expand a small "Freedom Fuel" research effort into a national "crash" program to advance the technology of hydrogen production and use. This multi-billion dollar effort – one of the few successful federal energy initiatives -- funds R&D on producing hydrogen from coal and accelerates commercialization of new fuel-cell technologies by U.S. companies.

But, overall, new technologies falter. Unexpected engineering challenges prove insurmountable. Environmental impacts of the new systems generate significant public resistance to their widespread use. Institutional failures in managing the commercialization process ensure a lack of success in the marketplace.

U.S. oil imports continue to grow, increasing more than 100 percent from 2000 to 2050, and putting severe pressure on other oil-importing countries. A worldwide economic slowdown reduces world oil demand, allowing oil prices to remain largely flat in constant dollar terms over the scenario period. The market share of imports in U.S. oil consumption increases in this scenario from about 55 percent in 2000 to 73 percent in 2050. To reduce the pressure on oil imports, federal policy promotes the introduction of fuel cell vehicles after 2020. By 2050, fuel cell vehicles capture almost two-thirds of new light-duty vehicle sales. Both natural gas demand and wellhead gas prices double during the scenario period. Imports of natural gas increase from about 7 percent to 25 percent of total demand.

In this environment, the federal government abandons any pretense of a cohesive national energy strategy, and retreats into crisis management. The volume of both public and private investment in R&D declines steadily and the prospect of deflation looms over the economy. The incessant string of severe stresses and periodic shocks slows the rate of economic growth in Big Problems Ahead. GDP grows at an average rate of 2.4 percent per year, from about $10 trillion in 2000 to $32 trillion in 2050. During the same period, energy demand increases at a rate of about 0.5 percent per year, from 100 Quads in 2000 to just 124 Quads in 2050.

In short, Big Problems Ahead is a chaotic future beset with shocks, stresses, and discontinuities. Economic growth is slowed worldwide. U.S.

energy policy is disjointed. Concerns about energy security keep everyone on edge. Rising U.S. oil imports increase U.S. dependence on unstable world regions. And U.S. responses to these challenges make it appear that the United States has become an arrogant and imperial player on the world stage, reducing the inclination toward international cooperation in many countries.

### *1.4 Technology Drives the Market*

Technology Drives the Market is a scenario in which a variety of forces converge to reshape the market architecture of the U.S. energy sector. The promise of commercial and environmental benefits from new technologies motivates state officials to reform regulatory policy and eliminate barriers that hinder commercialization of new technologies. Implementation of institutional and regulatory reform sets the new and improved technologies on a level playing field alongside mature technologies in U.S. energy markets, allowing incumbent companies in these markets to embrace the new technologies. Engineering advances in the design and development of efficient, low-emissions technologies capture the imagination of business leaders, state officials, and individual consumers. Private investment by U.S. energy companies combines with rapid technical progress and value shifts by U.S. consumers to drive the new technologies to rapid market acceptance and widespread commercial applications.

In *Technology Drives the Market*, state regulators overcome historical tendencies and work together. Early in this scenario, state leaders establish an integrated set of tariff policies for energy efficiency systems, renewable energy technologies, and distributed electricity generation schemes. State governments work together to implement standardized equipment requirements for connecting the new technologies to local utility grids. Net metering programs (currently implemented in more than a dozen states) spread across the country and facilitate arrangements in which on-site generators sell electricity back to the grid through simplified accounting transactions. Improved techniques for real-time load-flow analysis facilitate time shifting of local loads and the introduction of regional sub-networks of micro-grids. These local micro-grids lower the stress on aging transmission systems and increase the reliability of utility generating networks. Strict environmental permitting standards are applied to both new and traditional technologies, limiting the energy sector's impact on the regional and global environments.

Engineering advances play a key role in this scenario, improving the technical performance and reducing the effective costs of small, distributed, energy-producing technologies. In this scenario, we assume a large number of technologies achieve commercial success, including building-integrated photovoltaic power systems, medium to large wind machines (i.e., machines with rated capacity of 5 kW to 5 MW), small methane-reforming appliances (located at local fueling stations that produce hydrogen for fuel cells from natural gas), fuel cells for mobile and stationary applications, and biomass energy systems to produce both heat and electricity.

In the transportation sector, the most dramatic improvements emerge in the light-duty vehicle arena. Shifting consumer values place increasing importance on reducing the environmental footprint of each consumer, making hybrid gasoline-electric or diesel-electric cars appear much more "cool" to the average consumer than would a large, heavy inefficient, sport-utility vehicle. As this scenario progresses, the growing success of methane-reforming appliances coupled with the increasing reliability and durability of fuel cells in mobile applications leads to a growing market share for efficient, low-emissions vehicles.

As consumer purchasing preferences shift to small and efficient vehicles, oil demand in the U.S. transportation sector plummets while personal mobility is maintained. New hybrid vehicles use much less gasoline (or diesel) for the same amount of driving, while the new fuel cell vehicles derive their power from domestic natural gas. This has significant positive implications for energy security as the demand for imported fuel begins to decline steadily.

Imports of petroleum and petroleum products actually decline by almost 15 percent in *Technology Drives the Market*, from 24 Quads in 2000 to just 21 Quads in 2050. Imports of natural gas increase over the same period, but less than in any other scenario, reaching only 12 Quads in 2050. Driven by massive public and private investment in new technologies, the U.S. economy grows more rapidly in *Technology Drives the Market* than in *Big Problems Ahead,* a scenario in which continuing uncertainty depresses investment. Similar to *Cheap Energy Reigns Supreme,* GDP in *Technology Drives the Market* increases from $10 trillion in 2000 to almost $40 trillion in 2050. However, the effect of investment in efficient technology combines with shifts in consumer values and behavior to slow the rate of growth in energy consumption in *Technology Drives the Market.* Thus, the energy intensity of the U.S. economy improves significantly. Hence, this scenario is one in which a variety of forces converge to bring a host of advanced, efficient, low-emissions technologies to commercial readiness.

The introduction of these technologies is made possible by a sustained commitment to Research & Development among private investors and a dedicated effort on the part of state officials to lower the barriers to commercialization of new technologies. In addition, consumers recognize added value in technologies perceived to be clean, safe, reliable, and convenient. As a consequence, although the general economy grows rapidly and steadily in this scenario, primary energy use grows much more slowly than does the overall economy, reducing energy intensity over time as well as aggregate expenditures on energy.

## 2. CONCERNS ABOUT A SUDDEN SURPRISE COULD CHANGE THE GAME

Each of the four scenarios described above is one among many possible U.S energy futures. Though not inclusive of all possible outcomes, these four scenarios, taken together, represent much of the range of future possibilities. But more can be learned from these scenarios if a strategic challenge sufficient to motivate major change in the behavior of key actors is introduced. The response to this challenge can then be simulated and tracked in three additional scenarios (referred to in this study as "challenge and response" policy cases), allowing analysis of the impacts on the general economy and on key energy-related sectors.

### *2.1 Introducing a Strategic Challenge and Response*

The risk of abrupt climate change could plausibly represent one such challenge. Concerns about this low probability, high consequence event are not unreasonable in the face of recent scientific research. For the last several years, oceanographers and geophysicists have observed a change in the salinity of the North Atlantic Ocean and an associated slowing of the thermohaline circulation that is centered in an area west of the Norwegian Sea. These scientists warn that if the associated process called North Atlantic Deep Water (NADW) formation slows further or comes to a halt, human societies may face a period of abrupt climate change, with rapid cooling experienced in the New England and Mid-Atlantic regions of the United States, as well as in Northwest Europe. They suggest that the continued build-up of greenhouse gases due to the combustion of fossil fuels increases the risk, not just of global warming, but also of the extreme regional cooling that would be associated with a shutdown of the thermohaline circulation in the North Atlantic. Many scientists believe that an abrupt climate change could occur during the next several decades and merits attention from policymakers.

The basecase scenarios (*Cheap Energy Reigns Supreme, Big Problems Ahead,* and *Technology Drives the Market)* contain no explicit consideration of the risks of climate change or of controls on emissions of greenhouse gases. However, in the "challenge and response" policy cases, the potential for abrupt climate change is introduced as a major stressor or challenge. This study postulates that consideration of the possibility of abrupt climate change causes national policymakers to accelerate the implementation of substantial steps to slow the build-up of greenhouse gases (Baranzini, Chesney, and Morisset, 2003). In each of the challenge and response scenarios, U.S. policymakers implement a portfolio of energy policies designed to promote diversity in energy supply, decrease U.S. dependence on foreign oil, improve U.S. energy security, increase efficiency in all energy-intensive sectors of the economy through the introduction of conservation measures and advanced technologies, accelerate capital stock turnover particularly in the electricity and transportation sectors, sustain economic growth, and decrease $CO_2$ emissions resulting from energy supply and use.

Similar policies and measures are introduced in all three basecase scenarios (*Cheap Energy Reigns Supreme, Technology Drives the Market,* and *Big Problems Ahead)*, but are applied with differing degrees of stringency to produce the three "challenge and response" policy cases. This set of policies was not applied to *The Official Future, which is* used solely as a benchmark or reference case in this study. None of these challenge and response scenarios are intended to reflect likely outcomes, nor should the postulated response be seen as a policy recommendation. The scenario descriptions should be taken for their heuristic value only. In other words, they are intended to highlight the spread of possible outcomes and responses in ways that help policy makers better understand future interactions and outcomes. The response of key actors to these initiatives depends upon the fundamental dynamics and underlying logic of each scenario as well as on the conditions that are present when the policies are introduced. Hanson et al (2004) outlines the specific policies and measures implemented to achieve the emissions reduction targets of the challenge and response cases. As described above, the AMIGA model again was used to quantify the impact of the selected policies on key energy-related sectors of the economy in each "challenge and response" policy case. Table 1 above summarizes the key economic and energy indicators for each "challenge and response" policy case compared to its basecase scenario.

## 3. IMPLICATIONS AND CONCLUSIONS: LESSONS LEARNED

Several implications and conclusions can be drawn from a comparison of the basecase scenarios, the challenge and response policy scenarios, and the reference case.

### *3.1 Scenario analysis can be an important tool for investigating U.S. energy futures*

The pattern of future evolution for U.S. energy markets is highly uncertain at this time. Critical uncertainties include future rates of technological advance, levels of private investment in new technologies, strategies of foreign actors (especially oil suppliers), and directions of state and federal policy. A range of unexpected events or surprises may affect the ways that these uncertainties play out. Scenario analysis allows explicit consideration of these critical uncertainties and the dynamics of their interaction with the key driving forces affecting the evolution of U.S. energy markets. Quantification of the resulting scenarios allows direct comparison of the consequences that may arise as these scenarios unfold.

### *3.2 The range of feasible U.S. energy futures is broad, but energy use is expected to grow under all scenarios.*

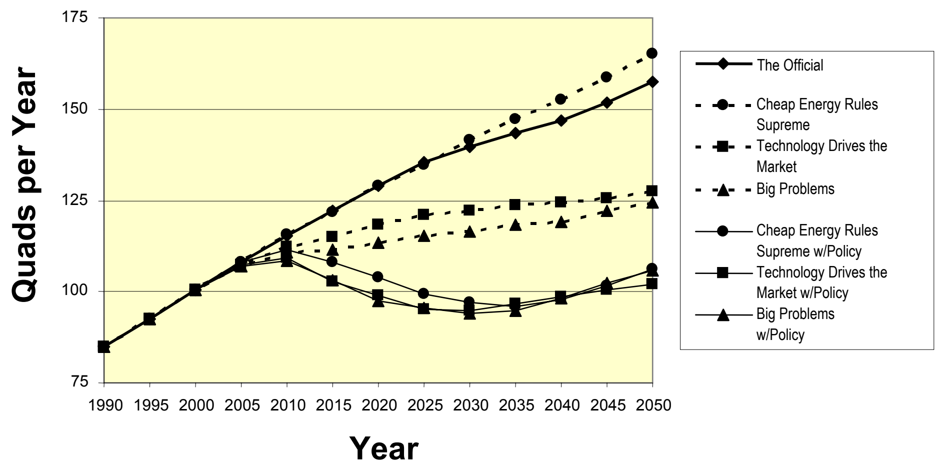
Interactions among the forces driving evolution of U.S. energy markets may lead to many different paths of technology development, market architecture, and consumer demand. Uncertainties persist concerning the interactions of these forces. Nonetheless, analysis of all three basecase scenarios, which span a broad range of possible paths, indicates that U.S. economic activity and energy demand will continue to increase in the period from 2000 to 2050 in the absence of specific energy policies to accelerate capital stock turnover and the commercialization of low-emissions technologies.

### *3.3 Introduction of policies to encourage capital stock turnover and accelerate the commercialization of high-efficiency, low-emissions technologies can significantly reduce future primary energy demand in the United States.*

Policies accelerating introduction of more efficient technologies and demand-reducing measures applied in the three challenge and response scenarios slow growth in primary energy demand. By 2050, primary energy demand remains close to the year 2000 level in all three policy cases. The corresponding increase in the three basecase scenarios and in *The Official Future* ranged from 25 to 60 percent. Figure 1 illustrates the trajectories of primary energy use in the challenge and response cases, and compares them to the higher trajectories of energy growth in the basecase scenarios.

**Figure 1**

**Primary Energy Use in the Basecase and Policy Scenarios**




### *3.4 Low energy prices can lead to high economic growth. But so can a smart investment path emphasizing energy efficiency improvements and advanced technologies.*

Each of the basecase scenarios investigated in this study involves continued and sustained economic growth — U.S. GDP grows at 2.4 – 2.8 percent per year from 2000 to 2050. In both the *Cheap Energy Reigns Supreme* and *Technology Drives the Market* basecase scenarios, GDP growth is at the high end of the range for the entire scenario, reaching approximately \$40 trillion in 2050. *The Official Future* attains just \$37 trillion, and GDP grows the least in *Big Problems Ahead*, to \$32 trillion. This demonstrates that in scenarios without substantial policy intervention, strong GDP growth can be sustained either by low energy prices or by continuing investment in advanced technology.

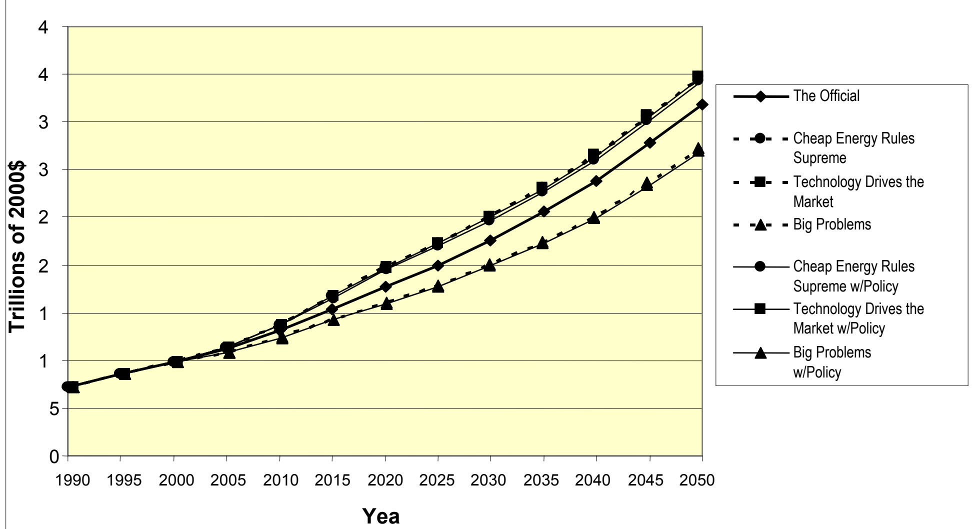
### *3.5 Policies introduced to improve energy efficiency and accelerate the introduction of new technologies do not appreciably reduce the prospects for economic growth.*

Surprisingly, despite the introduction of policies to promote capital stock turnover and to limit $CO_2$ emissions, GDP in the challenge and response cases reaches approximately the same levels in 2050 as is achieved in the respective basecase scenarios. The projected differences are only 0.3 to 1.3 percent after 50 years (see Figure 2 on the following page).

Smart policy and investment choices made today will accelerate the turnover of fully amortized capital stock and can stimulate substantial economic growth. A balanced portfolio of market-oriented policies would likely include a combination of efficiency or performance standards for vehicles, appliances, and industrial equipment; a cap-and-trade program for large stationary sources; and a series of information initiatives and barrier-busting policies to level the playing field for commercialization of new technologies.

Investments made today in critical energy technologies are likely to remain robust across a diverse set of possible futures and strengthen the prospects for economic growth.

**Figure 2**
**GDP in the Basecase and Policy Scenarios**




### *3.6 Public and private choices, along with external events, affect the cost of responding to future surprises*

One thing is certain: The United States will face surprises in the future, just as it has in the past. Some of those surprises may be unfortunate or even catastrophic. One such "game-changing" surprise is represented by the risk of abrupt climate change. Another such surprise might result from a complete cutoff of Middle East oil exports to the OECD, something that could be precipitated by a series of successful Islamic revolutions in the region.

Low fossil fuel prices will discourage investments in energy efficiency or new technologies and can make the task of responding to future surprises both harder and more expensive. Should a major, disruptive surprise occur, large investments in adaptive responses and a rapid transition to new energy technologies could very well become necessary. Such a rapid transition would be both more expensive and more disruptive if steps are not taken soon to decrease U.S. oil import dependence and to invest in advanced energy technologies and energy efficiency measures. In sum, this study shows that early expenditures can significantly reduce the costs of responding to unexpected problems in the future.

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