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U.S. Energy Scenarios for the 21st Century

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Prepared for the Pew Center on Global Climate Change

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Contents

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Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

The question of how U.S. energy supply and use—which account for over 80 percent of U.S. greenhouse gas emissions—will evolve over the next several decades is critical to developing sound U.S. climate policy. To answer this question, the Pew Center convened two workshops, including members of its Business Environmental Leadership Council and independent experts, to envision and analyze future energy scenarios for the United States, and to assess the implications of these scenarios for U.S. carbon emissions. The scenarios are:

- *Awash in Oil and Gas*, in which oil and gas are cheap, abundant, and reliably available;
- *Technology Triumphs,* in which the commercialization of climate-friendly energy technologies is accelerated through a combination of state policy, technological breakthroughs, public and private investment, and consumer interest; and
- *Turbulent World,* in which supply disruptions and energy security concerns lead to aggressive federal energy policy promoting domestic, low-risk resources.

Climate policy was deliberately excluded from these "base case" scenarios.

Carbon emissions increase under all these scenarios. *This points to the need for a mandatory carbon policy under a broad range of energy futures.* Carbon emissions increased much more under *Awash in Oil and Gas* than in the other two scenarios. This draws attention to the importance of climate-friendly energy technologies and climate-friendly energy policies in moving us toward a low-carbon future.

When a hypothetical mandatory climate policy was imposed on all three scenarios, it was most difficult to achieve under *Awash in Oil and Gas*, of medium difficulty in *Turbulent World*, and easiest in *Technology Triumphs*. This range of difficulty is due to fundamental differences in the base case scenarios. But the unmistakable conclusion is that under all scenarios, a mandatory carbon policy is necessary.

In the course of the analysis, the Pew Center and the Global Business Network also developed technology assessments revealing that a number of emerging technologies—such as carbon capture and geological sequestration, distributed generation, hybrid-electric vehicles, and hydrogen fuel cells—have the potential to yield multiple economic, environmental, and energy security benefits.

This report explores what *might* happen to U.S. energy supply and use in the future; the Pew Center plans to turn next to an exploration of what *ought* to happen. We will use these scenarios to test policy and technology options and identify those that are robust across a broad range of plausible futures. We hope that readers will join us in developing a shared national vision of policies, strategies, and investments that will reduce U.S. greenhouse gas emissions and promote U.S. energy security while maintaining economic growth.

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Note: Organizational listings are for identification only. Neither the findings nor the information contained in this report are meant to reflect the views or endorsement of any of the organizations listed here.

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Executive Summary

This study presents a set of scenarios describing three divergent paths for U.S. energy supply and use from 2000 through 2035. The scenarios presented here are not predictions; taken together however, these potential futures can be used to help identify key technologies, important energy policy decisions, and strategic investment choices that can enhance energy security, environmental protection, and economic development over a range of possible futures. To envision these scenarios and to draw policy-relevant conclusions from them, the Pew Center on Global Climate Change, working with the Global Business Network, convened two workshops with experts from the corporate, academic, and NGO sectors. The Pew Center also commissioned a set of technology assessments and joined with the Global Business Network to analyze the scenarios.

The trajectory of future U.S. economic growth, energy use, and carbon emissions will be a product of dynamic interactions among a complex set of driving forces, including technological advances, international events, energy and environmental policy, private investment, and consumer behavior. The interactions among these forces and their interplay with other social, economic, environmental, and cultural forces that stimulate change are not completely understood today. However, if the past thirty years are useful as a guide, it is likely that major surprises will occur between now and 2035.

The scenarios developed in this study reflect divergent trends in all of these driving forces. In brief, the three base case scenarios are:

- *Awash in Oil and Gas,* a scenario in which abundant supplies of oil and natural gas remain available to U.S. consumers at low prices. Energy consumption rises considerably, and conventional technologies dominate the energy sector. In this low energy price scenario, there are few incentives to improve energy efficiency and little concern for energy issues. Carbon emissions rise 50 percent above the year 2000 level by 2035;

- *Technology Triumphs,* a scenario in which an array of driving forces converge to accelerate the successful commercialization in the U.S. market of many technologies that improve energy efficiency and produce lower carbon emissions, and in which U.S. companies play a key role in the subsequent development of an international market for these technologies. Despite sustained economic growth and an increase in energy consumption, carbon emissions rise 15 percent above the year 2000 level by 2035; and

- *Turbulent World,* a scenario in which U.S. energy markets are repeatedly buffeted by developments both at home and abroad, with unsettling effects on energy prices and mounting threats to

U.S. energy security. High energy prices and uncertainty about energy supplies slow economic growth, and the country moves from one technological "solution" to another, finding serious flaws with each, until finally settling on a program to accelerate the commercialization of hydrogen and fuel cells. Despite slower economic growth in *Turbulent World*, carbon emissions rise 20 percent above the year 2000 level by 2035.

Climate change policy was deliberately excluded from these three base case scenarios; rather, the participants in the scenario development process formulated a hypothetical climate policy overlay. The policy overlay postulated a freeze of U.S. carbon dioxide (CO_2) emissions in 2010 and subsequent 2 percent per year decreases from 2010 to 2025, followed by 3 percent per year decreases to 2035. Like the base case scenarios, the policy overlay is neither a prediction nor a recommendation. To achieve the targeted emissions reductions trajectory and create the policy overlay cases, the same portfolio of primarily market-oriented policies and programs was imposed on each base case scenario.

Carbon dioxide emissions reductions achieved in other countries, carbon sequestration in plants and soils, and reductions in emissions of other greenhouse gases were beyond the scope of this analysis. Other analyses indicate that to minimize the cost of emissions reductions for the energy and energy-intensive industries, it is important to have flexibility in offsetting energy-related CO_2 emissions through international emissions trading, non-CO_2 greenhouse gas reductions, and carbon sequestration.

When the postulated policy overlay is applied to each of the base case scenarios, it modifies the pattern of energy technology development. For example, in the base case of the *Turbulent World* scenario, concerns about energy security stimulate a major national commitment to expanding production of hydrogen from coal and to accelerating the development of hydrogen fuel cells, both for transportation and in stationary power applications. In the policy overlay case for the *Turbulent World* scenario, the carbon constraint combines with growing public and private concerns about the security of energy facilities to stimulate demand for distributed generation (DG) and for combined heat and power (CHP) systems.

In the *Technology Triumphs* base case, new technologies already contribute to a slowing in the growth of carbon emissions. In the policy overlay case for *Technology Triumphs,* the carbon emissions limit forces faster reductions in oil demand, especially in the transportation sector, compared to the *Technology Triumphs* base case, resulting in accelerated market penetration by hybrid gasoline-electric and diesel-electric vehicles. Imposition of the carbon constraint in the policy overlay case expedites efforts to lower the barriers that typically hold back distributed generation, end-use efficiency improvements, and renewable energy technologies from large-scale commercialization in the United States.

In *Awash in Oil and Gas,* imposing carbon policies is more complex and more challenging. The base case scenario, built around cheap and abundant resources of oil and gas, includes little private investment in the technologies that improve end-use efficiency or reduce carbon emissions. Thus, meeting the carbon emissions target of the policy overlay introduces tremendous tension into this scenario. Major federal programs are needed to mandate carbon reductions and educate individual and industrial consumers about the climate consequences of their energy use. Yet cheap fuel encourages consumers to drive inefficient vehicles and stimulates air travel. Facing an exceedingly tight constraint on emissions and with little time to upgrade capital stock, public and private decision-makers move aggressively (but late in the scenario period) to develop carbon capture and geological sequestration technology so as to keep combustion-derived carbon dioxide out of the atmosphere.

Taken together, this scenario analysis revealed three important conclusions:

(1) *Climate change policy is needed to stem future emissions growth, regardless of which path the U.S. energy future ultimately takes.* In the absence of policies designed to reduce U.S. carbon emissions, these emissions increase over the next three decades in all of the base case scenarios, even those with optimistic assumptions about the future cost and performance of energy technologies.

(2) *Policy and investment decisions today, especially those that support key technologies, will have a significant impact on the difficulty of reducing energy-related carbon emissions tomorrow.* Early and sustained investment, engineering success, and consumer acceptance of innovative low-carbon and efficiency-improving technologies make the task of reducing emissions easier, as do energy security policies that reduce oil import dependence. Low fossil fuel prices make the task harder by encouraging high-carbon and energy-inefficient investments. Other scenario conditions, such as external events, play a major role as well.

3) *A portfolio of policies combining technology performance targets, market incentives, and price-oriented measures can help the United States meet complementary energy security, climate protection, and economic objectives.* Targeted policies can stimulate investment, accelerate the turnover of capital stock, and encourage emissions reductions. Emissions allowance trading, along with informational and other programs designed to address market imperfections, can lower the barriers to commercialization of efficiency-improving measures and new low-emissions technologies. However, policies designed to reduce carbon emissions can entail significant costs for the energy and energy-intensive sectors of the economy. Flexible program design, as well as successful development of major new technologies, can help to reduce these costs.

These principal conclusions are discussed below.

Absent a climate policy, U.S. carbon emissions will continue to increase

In the absence of a mandatory carbon cap, none of the base case scenarios examined in this study achieves a reduction in U.S. carbon dioxide emissions by 2035 relative to current levels. This is true even in the scenario with the most optimistic assumptions about the future cost and performance of energy technologies. Although the future is unlikely to unfold in precisely the manner described by any one of these scenarios, without climate policy

U.S. carbon dioxide emissions in 2035 are unlikely to be less than the 1,800 to 2,400 million metric tons of carbon represented in the three base case scenarios. Thus, slowing the buildup of greenhouse gases in the atmosphere will require significant, systematic, and sustained policy intervention in the United States.

In the base case scenarios, while U.S. population grows steadily, GDP increases significantly and pushes the rate of growth in aggregate energy demand beyond the rate of improvement in energy efficiency.[1] Total primary energy demand grows at an average annual rate that varies from 0.5 percent per year in the *Turbulent World* scenario to approximately 1.2 percent per year in *Awash in Oil and Gas.* These annual increases in primary energy use lead to energy consumption levels in 2035 ranging across the three base case scenarios from approximately 120 to 150 Quads (quadrillion British thermal units), up from 100 Quads in 2000.[2]

During the same period, U.S. carbon emissions increase from approximately 1560 million metric tons of carbon (MMTC) emitted as carbon dioxide[3] in the year 2000, reaching 1800 to 2360 MMTC in 2035. This is equivalent to an increase in annual CO_2 emissions of 15 to 50 percent above the 2000 level, and largely parallels the increase in primary energy use. Despite declining carbon intensity of the U.S. economy at an average annual rate of 1.8 to 2.6 percent, carbon emissions rise in all base cases. In the three policy overlay cases, which include mandatory carbon constraints, the carbon intensity of the U.S. economy declines more rapidly than in the base case scenarios, at an average annual rate of 3.6 to 4.2 percent, and by 2035 annual CO_2 emissions fall to almost 40 percent below the year 2000 level.

Choices made today will determine the difficulty of reducing carbon emissions

Many climate policy analyses create one base case and then overlay various policy options; this scenario planning exercise takes three different base cases and analyzes the effect of imposing the same policy overlay on each of them. Because the conditions of each base case scenario are different, achieving carbon reductions through the policy overlay is not equally difficult for all three scenarios. Aggregate costs to the economy of meeting the carbon emissions constraint differ by more than a factor of two among the scenarios; they are lowest in *Technology Triumphs* and highest in *Awash in Oil and Gas.*

The conditions of each scenario influence energy consumption and investment in that scenario, which in turn affect the level of carbon emissions. Each scenario illustrates a unique pattern of public policies, technological choices, and external events that affect prices, investment, consumption, and economic growth. Implementing climate policies modifies the energy mix, the pattern of technological development, and the composition and level of economic activity. For example, low oil and gas prices stimulate high levels of energy consumption and produce high levels of carbon emissions; low prices also discourage investment in energy efficiency-improving measures and carbon emissions-reducing technologies. Thus, the consumption and investment patterns in a scenario can lead to high carbon emissions and put the United States in a poor position to develop future technological solutions. Base case conditions that discourage energy consumption and favor investment in technological advances better position society to reduce carbon emissions.

More specifically, in *Technology Triumphs,* early and consistent investment in clean and energy-efficient technologies strengthens the economy and leaves the United States better positioned to reduce GHG emissions in the future. By contrast, in *Awash in Oil and Gas* much more aggressive and stringent policies are required to achieve the targets of the policy overlay because the economy starts from a high emissions trajectory. In addition, although the overall level of economic activity increases substantially in *Awash in Oil and Gas,* this scenario's growing reliance on imported oil significantly increases the likelihood that events in politically unstable regions of the world could lead to spikes in oil prices or temporary disruptions of supply.

A smart investment path today provides a greater capacity to respond to unexpected developments affecting future energy demand and supply. The scenario analysis identified several technologies as critical to the successful evolution of U.S. energy markets, enabling those markets to respond more effectively to uncertain future conditions.

The most important technologies include fuel cells, energy efficiency, CHP, renewable energy, DG, high-efficiency natural gas combined cycle power plants, hybrid electric vehicles, hydrogen production technologies, geological carbon sequestration, and integrated gasification combined cycle (IGCC) coal plants. Many of the electric power technologies are modular, allowing improved matching of supply and demand over relatively short time intervals. Modular technologies may improve the speed with which the energy sector can respond to changes, help to control risk, and maintain profitability in the U.S. energy sector.

Several technologies prove to be wise investments across the scenarios; others play key roles only under certain conditions. Natural gas consumption along with investment in energy efficiency measures, renewable energy technologies, and distributed generation increase in each scenario, both with and without climate policy. In all three policy overlay cases, hybrid-electric vehicles offer multiple benefits and emerge as a key near- or mid-term bridge to a hydrogen economy, and hydrogen makes an important contribution in the out-years. Hydrogen offers the possibility of numerous production pathways, using a variety of feedstocks. It is derived primarily from coal in *Turbulent World,* from natural gas in *Awash in Oil and Gas,* and from a variety of sources in *Technology Triumphs.* Distributed generation increases in each scenario, but to an extent and for reasons that vary by scenario. In the *Turbulent World* base case, investment in IGCC strengthens the role of coal in the U.S. energy sector. This early investment facilitates the commercialization of IGCC coupled with geological sequestration of CO_2, which enables coal to maintain a major role in *Turbulent World with Policy*, even in a carbon-constrained future. Bio-fuels and nuclear power play modest roles across the scenarios, both with and without climate policy.

A balanced portfolio of policies can help achieve multiple objectives

A balanced portfolio of market-oriented policies and performance standards—one that includes a carbon cap-and-trade program, incentives for technology development, strategies that remove barriers to new technologies, and efficiency standards—can help to achieve several objectives concurrently. These objectives include economic growth, energy security, and climate protection. These goals are often complementary: programs implemented for one of these reasons often contribute to the achievement of the other objectives as well. For example, in the *Turbulent World* base case, tough fuel economy standards designed to address energy security have the secondary effect of reducing GHG emissions. In *Turbulent World with Policy*, the carbon constraint incidentally but significantly reduces oil imports.

Many key technologies achieve multiple objectives. For example, distributed generation has energy security, environmental, and economic benefits. In both the *Turbulent World* base and policy cases, DG's increased market penetration is driven, in part, by its ability to reduce security risks for energy facilities. Many analysts believe that the small, often modular facilities used to provide distributed generation are less likely to be targets for terrorists than would be, for example, large, centralized nuclear power complexes or liquefied natural gas facilities. In *Technology Triumphs* with and without climate policy, engineering advances, state policy leadership, and sustained interest among private investors converge, contributing to nationwide efforts aimed at breaking the barriers to commercialization for "disruptive" new energy technologies. In *Awash in Oil and Gas,* the drivers include electric grid congestion caused by rapid electricity demand growth as well as interest in power quality[4] for specialized industrial applications and new consumer gadgets. In each of the policy overlay cases, relative to the respective base case, the efficiency benefits as well as the low-carbon characteristics of some DG and renewable energy technologies accelerate their penetration. Several of the most important energy efficiency and low-carbon technologies are cost-competitive today in specific applications. These include many energy efficiency measures in the buildings and transportation sectors, wind power plants, CHP, and combined-cycle turbines. Other important technologies are not yet cost-competitive in the U.S. energy market, including carbon capture and geological sequestration, photovoltaic power systems, and fuel cell vehicles. Full-scale commercialization of these critical technologies requires public policy to sustain investment in technology and market development.

Commercialization and market penetration of key technologies in the policy overlay cases are facilitated by various policies, strategies, and investments. Federal and state initiatives include renewable portfolio standards, fuel economy and air quality requirements, national electric grid interconnection standards, and aggressive R&D investment in hydrogen and fuel cell technologies. Private investment in emerging energy technologies also plays a critical role in all scenarios. This is especially true in the case of a major transition to use of hydrogen as a fuel, which requires sustained and coordinated investment in hydrogen production, transportation, and distribution infrastructure, as well as in fuel cell vehicles. Rapid commercialization of renewable and distributed electric generation also depends on new investment, but is greatly facilitated by removing institutional barriers to their use and by recognizing the full value contributed by these technologies to the operation of integrated electric grids. Because the time lag from technological breakthrough to commercialization is long, it is essential to initiate these investments early on and sustain them over time.

The hypothetical policy overlay emphasizes "barrier busting" policies and programs to remove institutional obstacles and lower the barriers to commercialization of new technologies. For example, expenditures on informational and educational programs can increase awareness of emerging technological opportunities and increase the ability of U.S. society to respond to unexpected changes in energy markets. Institutional reforms, such as uniform electric grid interconnection standards, facilitate the market penetration of disruptive technologies such as distributed generation and building-integrated photovoltaic power systems. By putting investment in energy-efficiency measures and carbon emissions-reducing technologies on a more equal footing with conventional energy supply technologies, such programs and policies help to ensure fair competition and increase the likelihood that investment moves toward the technologies that have the best long-run return for U.S. society.

In sum, this scenario exercise suggests that in the absence of a mandatory climate policy, U.S. carbon emissions will continue to increase. Policy is needed to encourage investment in climate-friendly technologies and to pull these technologies into the marketplace. Policy and investment choices made today will determine the difficulty of reducing carbon emissions in the future. A smart investment path today provides a greater capacity to respond to surprises tomorrow. A portfolio of technology performance standards and market-oriented policies can stimulate investment, accelerate capital stock turnover, reduce carbon emissions, and enhance energy security across a wide range of possible energy futures.

I. Introduction

The pattern of U.S. energy supply and use affects the global environment, national security, and the strength of the economy. The burning of fossil fuels releases carbon dioxide (CO_2) into the atmosphere and significantly contributes to the risk of long-term climate change. The United States is increasingly dependent on oil from the volatile Middle East and on other unstable regions of the world. The events of September 11, 2001 have elevated concerns about the vulnerability of energy facilities and about the implications of oil price volatility for the U.S. economy. The collapse of the Enron Corporation, the California electric sector restructuring debacle, and the resulting political and regulatory fallout roiled the U.S. electricity sector. These developments raised questions about whether electricity market restructuring will continue, and whether a more efficient and competitive U.S. energy market will evolve in the near future.

In the context of these emerging and continuing challenges, the Pew Center on Global Climate Change invited a group of 25 senior executives from its Business Environment Leadership Council (BELC), as well as experts from the research, NGO, and other communities, to envision a set of future scenarios for energy use in the United States. The Pew Center asked the Global Business Network (GBN) to lead this scenario development exercise.

Scenarios are not predictions or forecasts of the future. Many people and organizations talk about scenarios, and the word has taken on a range of different meanings. In GBN parlance and in this Pew Center exercise, scenarios are tools used for exploring an uncertain future. Well-designed scenarios offer a systematic way of illuminating different paths to the future and highlighting the forces that may drive different outcomes. Scenario narratives resemble a set of stories about the way the future might unfold, built around carefully constructed plots that highlight key elements. Once the storyline has been developed, various analytic tools can be used to quantify the specific elements or relationships among driving forces and to investigate the dynamics of their interactions.

Scenarios help individuals, businesses, and institutions to take a long view in a world of great uncertainty, allowing them to plan for the future when they cannot know all of the challenges that tomorrow will bring. Those who study scenarios can identify and evaluate the choices they face and expand their understanding of ways in which those choices may vary if different combinations of events occur. Scenario planning is about making choices for strategic investments and public policy today, fully aware of persistent uncertainties about the future.

This study focuses on a set of scenarios concerning U.S. energy use, economic development, and CO_2 emissions from 2000 to 2035. These scenarios highlight several existing and emerging technologies, along with key policy decisions and strategic investment choices that affect U.S. economic growth, atmospheric CO_2 buildup, and the nation's energy security.

The scenario-building process involved two workshops with members of the BELC and selected outside experts. These workshops were convened by the Pew Center and facilitated by GBN. The process provided a tool for ordering perceptions about alternative future environments in which public policy and private investment decisions might shape the evolution of U.S. energy markets. It offered a structured forum for discussing the driving forces and key uncertainties affecting U.S. economic development, possible patterns of future U.S. energy supply and use, and the evolution of key technologies whose commercial deployment might significantly affect future greenhouse gas (GHG) emissions.

Scenarios tell stories that are credible, relevant, feasible, and provocative. The Pew Center scenarios illustrate three *possible* futures; none are forecasts or predictions of future events, and no probabilistic estimates are made or implied about whether any of these futures will occur. Neither the Pew Center nor GBN endorses any particular scenario or view of the future. The value of these scenarios will be their ability to stimulate decision-makers to explore alternative views of the U.S. energy future and to facilitate strategic planning in uncertain times.

To quantify and analyze the implications of these scenario narratives, economists and energy analysts at Argonne National Laboratory employed a highly disaggregated computable general equilibrium model of the U.S. economy (called the All Modular Industry Growth Assessment model, or AMIGA). The model was modified and adapted to provide an illustrative quantification of the scenarios, to simulate a portfolio of policies, and to investigate their impacts.

The quantitative results of this study are dependent upon the assumptions made and the model used in this project.[5] Modeling of the scenarios was conducted in order to ensure internal consistency and to assess feedbacks on energy supply and demand that could affect emissions paths in each scenario. Modeling of the policy overlay was done not to predict the future but rather to provide insight into the relative impacts that could result from efforts to achieve the identified emissions targets.[6] The modeling and assumptions do not necessarily reflect the views of all workshop participants.

The layout of the report is as follows: Section II outlines the basic scenarios developed in this study and the policy interventions that were analyzed during the scenario-building process. Section III investigates the implications drawn from the scenario analysis. Section IV highlights the conclusions drawn from this scenario-planning exercise. In addition, the appendices in the web-based version of this report include assessments of key emerging energy technologies as well as details of the AMIGA model and its outputs.

II. Three Possible U.S. Energy Futures

The range of possible futures for the United States is broad, and precise outcomes cannot be predicted. Future U.S. energy use, economic growth, and carbon emissions could vary over a substantial range, depending on how key driving forces interact. The three Pew Center scenarios were developed to explore how this might play out. Among the most important of these driving forces are:

- Population growth;
- Demographics and land use;
- Private investment decisions and cost breakthroughs on key technologies;
- Individual decisions concerning consumption, lifestyle, and the willingness to adopt new technology;
- Public policy choices concerning energy strategy, technology development, market transformation, and environmental protection;
- The behavior of foreign actors, especially those in regions from which the United States imports significant quantities of energy; and
- The willingness of the U.S. government and the general public to tolerate continued U.S. dependence on energy imports from unstable regions of the world.

The three scenarios explored in this study diverge from one another due to differences in these driving forces (excluding U.S. population growth, which was held constant across the scenarios). In the first scenario, *Awash in Oil and Gas,* U.S. energy security is not an important issue. Conventional energy technologies dominate the market while energy prices remain low. In the second scenario, *Technology Triumphs,* state policy converges with business investments in new technologies, technological breakthroughs, and consumer preferences to drive the commercial success of a suite of energy efficiency-improving and low-carbon emissions technologies. The final scenario, *Turbulent World,* envisions a future in which energy security is of paramount concern, leading eventually to a national program on the scale of the Apollo “moonshot” to shift the United States from oil dependence to a hydrogen economy.

A. Awash in Oil and Gas

Overview

Awash in Oil and Gas *is a market-driven scenario in which abundant supplies of oil and natural gas are available to U.S. consumers and cheap energy remains a staple of the U.S. economy.* Although short-term oil and gas prices fluctuate sharply, global oil and North American natural gas prices, on average, decline (in constant year-2000 dollars) over the course of this scenario. Conditioned by low prices, consumers freely use as much energy as they can afford. Houses are heated above 70ºF in the winter and cooled to below 68ºF in the summer. Cars become havens, personalized environments in which conditions are plush, secure, and completely controllable. Commuters drive longer distances to work, shoppers spend more time traveling to regional malls, and the average number of miles traveled annually increases almost by a factor of two for cars and light trucks. Construction of new infrastructure keeps pace with individual demands for personal mobility. Highways and airports continue to be publicly subsidized, and parking is cheap.

Federal energy policy is guided by a commitment to minimal intervention in energy markets, but continues to encourage investments in energy supply. Close control of federal fiscal policy and careful attention to managing inflation lead to sustained economic growth throughout this scenario, dampening the oscillations associated with traditional U.S. business cycles. U.S. consumers do not call for leadership on energy issues and largely ignore the climatic consequences of energy supply and use.

Due principally to the growing population, increasing levels of economic activity, rising demands for electricity, and increased use of fossil fuels (particularly in the transportation sector), U.S. annual economy-wide carbon emissions grow over 50 percent in *Awash in Oil and Gas,* from about 1560 million metric tons of carbon equivalent (MMTC) in 2000 to nearly 2360 MMTC in 2035.

A Buyer's Market for Oil and Gas

Early in Awash in Oil and Gas, *abundant supplies of conventional oil and natural gas become available to the American market at historically low price levels.* From 2000 to 2010, several key members of the Organization of the Petroleum Exporting Countries (OPEC) increase their oil exports. Full-scale commercial production of Iraqi oil comes back on-stream, increasing to almost 4 million barrels per day by 2010.

In this same time period, Russia and Mexico accelerate domestic oil field development. Russia increases oil exports to Europe and Japan, while Mexico expands oil sales to the United States. Both Russia and Mexico ignore OPEC's pleas for "discipline" on oil prices, lowering their prices to increase their share of the global market. These actions put pressure on OPEC members to ignore the cartel's calls for solidarity on oil prices and for disciplined adherence to agreed caps on production. The increased production by Russia, Mexico, and other non-OPEC producers maintains low prices for oil and petroleum products in the United States. North American producers expand production from Canadian oil sands and intensify their efforts to develop frontier oil resources. As the competitive pressure intensifies, some relatively higher-cost oil producers also increase output, putting additional downward pressure on prices, which decline to less than $23 per barrel as early as 2005 (in year 2000 constant US$).[7] This compares to a range of $26 to $30 per barrel for the average daily spot oil price in 2000.

Concerned that Middle Eastern suppliers will escalate this competition into a price war, major international oil companies and non-OPEC producers invest in technology to lower the exploration, development, and lifting costs of their resources. Steady technological advances in oil exploration and production technology lower lifting costs for conventional resources. Application of this new technology combines with new techniques for remote sensing and seismic exploration, significantly increasing historic estimates of proven reserves. U.S. oil policy continues along a business-as-usual path, focusing on maintaining access to cheap foreign supplies. With the world awash in oil, state governments object to the federal government's efforts to loosen regulatory controls on domestic oil drilling and to offer incentives for development of recent discoveries along the Outer Continental Shelf and along Alaska's Arctic Plain. Meanwhile, historic trends continue as U.S. oil production in the lower 48 states steadily declines.

From 2005 to 2015, the amount of natural gas used to generate electricity increases. Despite market restructuring of the electricity sector, electricity prices rise moderately with the increasing use of natural gas. The wellhead cost of North American natural gas rises to $2.70 per thousand cubic feet in 2015, and reaches around $4.00 per thousand cubic feet (mcf) by 2035.

Canadian and Mexican natural gas exports to the United States grow steadily throughout this scenario. Political concerns about possible price spikes and interruptions of gas supply during the winter heating season cause the U.S. federal government to negotiate expanded access to Canadian and Mexican gas supplies. The federal government also removes restrictions on natural gas exploration in the Arctic and on federal lands in the Rockies. These incentives are coordinated with a restructuring of federal tax policy, encouraging expanded private sector investments in North American gas supply infrastructure.

In response to the new federal policies, private investment in exploration and production of Arctic and unconventional gas, which had begun in the 1990s, expands rapidly, doubling between 2005 and 2010. These early investments in frontier gas lead to the discovery and development of large exploitable fields both in the Arctic and in the Rocky Mountain West. Investments in exploration technology and improved transmission infrastructure lead to declining marginal costs for new gas and allow gas producers rapidly to expand production of both Arctic and unconventional gas. The contribution of domestic unconventional gas resources—including coal-bed methane, tight gas sands, and shale gas—increases as the exploitation of new basins becomes cost-effective early in this scenario. Overall, North American gas supply increases from approximately 23 Quads in 2000 to 40 Quads in 2020.

In this scenario, new arenas of competition stimulate technological innovation, mainly in the upstream portions of the oil and gas sector. As new producing regions open, new players enter the global energy market. This creates increased tension, competition, and instability for OPEC. It also stimulates increased integration among the energy sectors of the United States, Canada, and Mexico.

Low Prices Lead to Increasing Market Share for Oil and Natural Gas

The U.S. economy continues to undergo its historical structural shift from manufacturing to service industries in Awash in Oil and Gas. The overall energy intensity of the economy (as measured by the amount of energy consumed per unit of gross domestic product or GDP created) decreases steadily in this scenario, as it does in each of the other base case scenarios. Nonetheless, abundant supplies and cheap prices for oil and gas help these fuels to capture an increasing share of U.S. energy markets.

Low average energy prices encourage some increased activity in energy-intensive U.S. manufacturing industries. However, historic declines in output from the domestic steel, aluminum, cement, and chemicals industries continue, as these industries shift from production of bulk commodities to manufacture of high value-added, engineered products. Although gross physical output from and employment in these industries falls relative to year-2000 levels, the profitability of these industries per ton of output increases significantly. The improved profitability results from a combination of factors: investments in energy efficiency, the waste-reducing effects of computer-aided engineering, rising labor productivity, and a shift to higher value-added products.

The abundance of cheap oil and gas encourages local resistance to construction in "green field" locations of energy facilities that are viewed as dirty, dangerous, or local eyesores. The response, "Not in My Backyard," (sometimes referred to as NIMBY) reflects the belief among many citizens that there is no need to allow increased exposure of local communities to new risks or added inconvenience from energy project development as long as there is more than enough energy available and prices remain low. Some expansion is allowed at existing "brownfield" sites, and in general, natural gas is recognized as sufficiently important and clean that it overcomes local resistance to new natural gas pipelines.

Electricity Demand Expands, Natural Gas Sweeps the Market

Low energy prices, a lack of government initiatives to reduce energy use or increase efficiency, continued consumer demand for larger homes, and increased requirements for climate control in buildings all contribute to steadily increasing electricity demand in this scenario. Air conditioning and heating systems are built into all new buildings, increasing electricity demand for space conditioning, particularly in the residential and commercial sectors. Manufacturing automation becomes more pervasive, with correspondingly higher electricity input to many industrial processes. Increasing demand for electricity and higher peak load levels put added pressure on the existing transmission system in this scenario. Some additional transmission capacity is built, but at a relatively high cost. The high cost of building new transmission infrastructure makes distributed generation increasingly attractive in this scenario.

Early in the scenario, virtually every commercial office environment nationwide incorporates a high-speed local area network, and virtually every desk or workspace contains a personal computer.

Consumers are drawn to all manner of electric and electronic devices. Personal computers link home entertainment centers with telephone, fax, e-mail, and security systems. By 2010, most family homes in the United States have more than one personal computer.

Modern, high-efficiency, gas-fired, combined-cycle power plants meet the incremental growth in electricity loads from 2000 to 2035 and pick up most of the load that is shed by retiring coal and nuclear plants. Because the fuel mix shifts from coal toward gas for electricity generation, emissions from the power sector grow somewhat less rapidly in this scenario than they would if the fuel mix in the electricity generation sector remained unchanged.

Conventional coal continues to play an important role in fueling the electricity sector in this scenario. Federal policy on domestic coal production continues unchanged. Most domestic coal-fired power stations operating in 2002 are maintained and continue to run as long as their operating costs are lower than the combined construction plus operating costs of the next-cheapest alternative, which is new gas-fired plants. In 2020, coal consumption remains approximately equivalent to the year 2000 level (23 Quads). By 2035, nearly 30 percent of the coal-fired generating units that were operating in 2000 are retired. These units, which produced about 20 percent of the kWh generated from coal in 2000, are mostly older, smaller, and less efficient plants than the average of the capital stock. These plants cannot compete economically with electricity produced from cheap natural gas burned in advanced, high-efficiency, combined-cycle turbines.

In order to continue generating low-cost power from fully amortized nuclear plants, the U.S. Congress re-authorizes the Price-Anderson act.[8] With the reauthorization of the act, life-extension programs sustain most of the commercial nuclear power stations operating in 2002. A small number of nuclear generating stations are retired during *Awash in Oil and Gas,* and maintenance on remaining plants increases scheduled downtime. Despite the increased demand for electricity, no new commercial nuclear power plants are built in the United States during this scenario, because they are assumed to continue to be much more capital intensive[9] and take much longer to build than new natural gas plants or other alternative technologies. Electricity generation from commercial nuclear plants declines by approximately 10 percent from 2000 to 2020 and then at an average annual rate of 1 percent per year from 2020 to 2035, falling to approximately 75 percent of the year 2000 levels by 2035.

Customer demand for enhanced reliability, the high cost of new transmission lines, and public concerns about local air pollution stimulate a modest amount of private investment in improved end-use efficiency, fuel cell technologies, renewable energy systems, and distributed generation, despite low energy prices. Most of the initial investment in distributed generation involves oil- or gas-fired technologies, including advanced internal combustion engines (ICEs), cleaner diesels, and microturbines. However, in the absence of any substantial federal or state incentives, renewable energy and DG technologies are slow to develop and penetration is limited to small niche markets. These technologies do not capture a larger segment of the electricity market because of the relatively low price of electricity generated with cheap and abundant supplies of natural gas and coal.

Conventional Cars and Trucks Rule the Roads

Light-duty vehicles are responsible for the largest fraction of energy consumption and carbon emissions in the transportation sector, which as a whole contributed about one-third of U.S. carbon emissions in 2000. In *Awash in Oil and Gas,* low prices and a plentiful supply of oil strengthen the market dominance of conventional cars and trucks. The availability of gasoline, compressed natural gas, and diesel fuel at historically low prices limits the development of domestic biomass-derived liquid fuels to less than one Quad by 2035. In general, low fuel prices discourage innovation and improvements in vehicle efficiency, but there are some exceptions. Hybrid gas-electric vehicles make a slow but steady penetration into the light-duty vehicle market. As pickups and other light trucks get larger and heavier over time, an increasing share of these vehicles are powered by diesel engines, increasing on-road fuel efficiency of the new vehicles in this class. Progress on fuel efficiency improvements is slow, however, even for hybrids in this scenario.

In *Awash in Oil and Gas,* most American families own at least one car or truck for each driving-age adult. With unlimited access to cheap gasoline and continuing concerns about the security of air travel, Americans begin to take their entertainment on the road, driving hundreds to thousands of miles for vacations and recreation. Purchasers of light-duty vehicles gravitate toward advanced power train technologies and larger, more muscular cars equipped with more complex, power-guzzling "gadgets."

Increasing local traffic congestion, combined with the convenience of tax-free purchasing on-line, encourages individuals and companies to increase the volume of Internet-based purchasing, leading to more orders for delivery of goods by airfreight and by truck. The share of freight traveling by rail shrinks constantly as efficient package-handling systems and ever-larger, long-haul trucks reduce the cost of moving parcels and commodities. Trucks capture a growing share of ground freight shipments.

Consumer demand for single-family housing combines with low gasoline prices and land-use policies oriented toward suburban sprawl to strengthen historical trends toward lengthening commute distances. This process also accelerates the conversion of agricultural areas to residential sub-divisions.

Long commute distances combine with growing amounts of leisure and personal travel by car to increase total vehicle miles traveled annually by light duty vehicles. With drivers facing increased idling in heavy traffic, on-road vehicle efficiency declines, and fuel consumption increases. The results include high levels of road congestion, persistent pockets of local air pollution, and increasing GHG emissions.

The U.S. government's passenger car and light truck standards for Corporate Average Fuel Economy (CAFE) remain unchanged from 2010 to 2035. Light trucks, including sport-utility vehicles (SUVs), remain in a regulatory category separate from passenger vehicles, despite their frequent use as family cars.

Limited Momentum for Quality-of-Life Issues

In Awash in Oil and Gas, *new federal policies to control air pollution are limited to the regulation of conventional pollutants from electric utilities.* In this scenario, the federal government does not impose any new regulations for criteria air pollutants that would require reductions in vehicle emissions. No new federal energy efficiency standards for vehicles, residential appliances, or industrial equipment are promulgated.

Quality-of-life issues emerge in 2015, initially reflected in local efforts to limit congestion with measures to control sprawl, improve town planning, limit car traffic in central cities, and develop or renovate regional mass transit systems. But many localities resist these efforts due to the continuing American love affair with cars fueled by cheap oil. Energy and food remain relatively inexpensive, and most Americans accept the environmental impacts of consumption as just one part of the price of progress.

Summary

Awash in Oil and Gas *is a scenario in which the U.S. energy sector is left largely to market forces.* Low prices and abundant availability of oil and gas discourage strategic thinking about energy by U.S. policymakers and limit efforts to regulate the environmental impacts of energy supply and use. Americans consume whatever they can afford to buy. Technological innovation in energy supply and use is generally limited to the upstream oil and gas sector. Concerns about U.S. oil import dependence or the consequences of U.S. consumption patterns for those outside the United States are rarely mentioned. As a result of significant GDP growth and rising electricity demand, even with expanded use of natural gas, annual U.S. CO_2 emissions increase to approximately 2400 MMTC in 2035 (approximately 50 percent above the year 2000 level).

Table 1

Timeline for Awash in Oil and Gas Base Case

2005-2010	• Key OPEC members increase output, seeking to protect market share; world oil price falls to $23 per barrel in 2005 • Rapid expansion of exploration activity in North American frontier basins
2005-2015	• Sustained investment in North American natural gas development is accompanied by continuous improvement in upstream technology • Availability of cheap fuels encourages expanding car ownership and increasing average annual vehicle miles traveled
2010-2015	• New technology makes North American frontier gas resources commercially competitive; new fields come on-stream; complementary transmission and distribution infrastructure investment increases
2015	• Quality of life issues emerge, but have little real impact • Natural gas prices are about $2.70 per thousand cubic feet
2020	• U.S. natural gas consumption increases to 40 quads
2035	• 70 percent of coal plants operating in 2000 are still operational • Gas-fired power plants have captured most of the new load demand as well as the load displaced from retired coal and nuclear plants

B. Technology Triumphs

Overview

Technology Triumphs *is a scenario driven by market forces, technological innovations, and policy decisions.* A variety of new energy technologies achieve commercial success, fulfill customer demands, and become the engine of growth for a sustained expansion of the U.S. economy. *Technology Triumphs* is driven by the convergence of four linked forces:

- State policies and regulatory standards "raise the bar" on engineering and environmental performance by energy technologies, with federal acquiescence;
- Public and private research on new energy technologies leads to significant engineering advances;
- Private investment supports the commercialization of these emerging technologies; and
- Purchasing decisions by individual consumers and industrial customers are shaped by preferences for technologies that incorporate a package of specific attributes.

Federal R&D investments support the development of new efficiency-improving and carbon emissions-reducing technologies. State policy decisions promote the commercialization of these technologies but lead to a fragmented market with disparate standards from region to region. Federal energy and environmental policy follows state policy decisions and attempts to unify these markets. Successful commercialization of new energy technologies opens new export markets for U.S. manufacturers and reduces the U.S. contribution to air pollution and global warming. Despite rapid and sustained economic growth, primary energy use grows by less than 25 percent while economy-wide carbon emissions increase by 15 percent in *Technology Triumphs,* from 1560 MMTC in 2000 to just under 1800 MMTC in 2035.

States Raise the Bar, U.S. Manufacturers Clear the Hurdle

State regulatory decisions on energy policy, facility siting, and air quality issues converge with customer preferences and investor decisions to influence the direction of U.S. energy market development throughout Technology Triumphs. In particular, state-based initiatives encourage the development of improved energy supply and end-use technologies by setting rigorous standards for efficiency and placing stringent limits on air pollutant and GHG emissions. Several states implement increasingly stringent air emissions standards for new stationary sources, modeled on New Hampshire's current multi-pollutant legislation. State-based standards for new vehicles emerge first in California, requiring vehicle emissions reductions of 25 percent for CO_2 in 2020, compared to average year-2000 levels. The latest California vehicle standards for CO_2, hydrocarbons, particulate matter, oxides of nitrogen, and carbon monoxide are adopted by a growing number of other states in *Technology Triumphs.* This occurs first in New England

and then spreads up and down the country's east and west coasts. Vehicle manufacturers respond by developing a variety of new drive-trains, including advanced gasoline and diesel internal combustion engines (ICEs), hybrid gasoline-electric and diesel-electric vehicles, and fuel cell cars.

More states introduce renewable portfolio standards (RPSs), requiring specified percentages of electricity generation to come from solar, wind, and biomass technologies. States with large wind resources, such as Texas and North Dakota, tend to attract more investment in wind, while states with large supplies of agricultural residues and biomass (such as Iowa, Nebraska, and Kansas) encourage the development of biomass energy systems.

Regional resource diversity (along with variations in state-based standards and siting regulations) shapes the portfolio of energy technologies that are most likely to make a significant contribution for each state. State governments make a concerted effort to expand the use of renewable energy technologies and encourage the development of fuel cells. The process of selective development and targeted marketing gives unique regional characteristics to the mix of technologies that penetrate the U.S. energy sector.

Not wanting to be excluded from major regional markets, progressive American companies respond actively to these state-based initiatives. U.S. manufacturing companies rely on techniques of mass customization pioneered by "new economy" companies like Dell Computer. These techniques allow companies to improve their production efficiency, reduce inventory costs, and fine-tune their products to meet consumer requirements for safety, product quality, reliability, convenience, and the absence of adverse environmental impacts. Regional differences play a particularly important role in the design of DG systems. The process of interactive product development and carefully targeted marketing increases overall energy efficiency and accelerates the commercial deployment of new energy supply and end-use technologies.

Decision-makers in the industrial sector also respond. Many industrial energy consumers work with Energy Services Companies (ESCOs) to identify and implement innovative energy solutions. Corporations find competitive advantage in moving toward combined heat and power (CHP). Large power purchasers stimulate investment in "green power." More and more companies want their buildings to be green, both to enhance their corporate image and to save energy costs. Green designs and renovations go mainstream, becoming typical of even the most conservative architects and engineers.

Federal energy policy throughout *Technology Triumphs* is guided by a philosophy of minimal intervention in domestic energy markets, facilitating rather than driving technology development. From 2005 to 2010, as states continue to follow individual approaches to restructuring of retail electricity markets, federal policy focuses on completing the process of restructuring the wholesale electricity market that was begun in the 1990s. After 2010, federal leadership on energy issues is largely confined to the activities of the Federal Energy Regulatory Commission (FERC), which struggles to rationalize and upgrade the national electricity transmission system and to coordinate the development of Regional Transmission Organizations (RTOs) with their Canadian counterparts. From 2015 on, the emphasis in federal policy shifts toward creating additional tax credits for purchases of new or improved technologies and to removing institutional barriers to the commercialization of DG technologies (see DG technology assessment in Appendix B). Concurrently, federal policy-makers introduce a set of national policies and standards endorsing earlier state decisions, encouraging DG but remaining sensitive to the diversity of regional energy markets.

States' Strategic Vision Helps Americans to Live Better Electrically

Electricity demands in Technology Triumphs *are not met by any single technology.* State energy policies encourage a broad range of electricity supply strategies, including increased reliance on natural gas, DG, renewable energy technologies, and energy efficiency measures.

State initiatives facilitate the commercialization of DG technologies. These initiatives include early promulgation of simplified interconnection standards, policies on facility siting that favor CHP and the cleanest technology options, performance standards requiring the use of advanced air pollution control technology in all electricity supply systems, and the development of consistent statewide and regional tariff policies.[10]

The expansion of net metering[11] encourages electricity customers to sell excess on-site power directly back to the utility grid, rendering more DG options cost-competitive. Implemented in more than 30 states as of 2002, net metering spreads nationwide by 2005 and becomes one element of a common national tariff policy that is implemented in 2015. Similarly, national interconnect standards and national emissions standards for DG are implemented midway through the scenario period. In the wake of these measures, the commercialization of fuel cells, biomass-fired CHP systems, solar and wind energy technologies, and energy efficiency systems are encouraged throughout the U.S. market, with market penetration varying by state and by region.

From 2003 to 2015, California promotes public-private partnerships to develop fuel cells. The California Fuel Cell Collaborative implements a major procurement initiative for stationary fuel cells, and California accelerates the commercialization of this technology by easing permitting requirements and facilitating changes in fire safety codes. The state also encourages investment in fuel cell related infrastructure through changes in the tax code and by working with municipal governments to simplify zoning restrictions. Private firms respond to these market transformation initiatives by accelerating production and commercialization of stationary fuel cells in both CHP and electricity supply applications.

Similarly, state RPS initiatives accelerate the development of renewable energy technologies. Many states allow interstate trading in renewable energy (especially electricity produced from solar and wind electric systems) well before a national renewable energy policy is put in place. The wider deployment of solar and wind technologies also helps utilities to acquire operational experience with integrating renewable energy into their systems through new dispatch and storage strategies, improving the commercial prospects for other utility-integrated intermittent generating technologies.

Cogeneration systems become increasingly prevalent in industry and in large commercial facilities in *Technology Triumphs.* From 2010 onward, high-temperature fuel cells (such as phosphoric acid, molten carbonate, and solid oxide fuel cells) are coupled with microturbines and widely used to provide on-site heat and power in shopping malls, schools, hospitals, and small factories. New state-based policies on utility buy-backs[12] encourage many large energy consumers to self-generate. Utilities respond to the threat of losing these valuable customers by offering to build, own, and operate natural gas-fired cogeneration units on the sites of their large commercial customers. By 2010, large new CHP systems generate approximately 95 terawatt-hours (TWh) per year, equivalent to approximately 13 percent of the nationwide electric load growth that occurs in *Technology Triumphs* between 2000 and 2010. By 2035, CHP systems contribute approximately 1600 TWh per year of electricity.

Electricity output from commercial nuclear plants is fairly constant throughout *Technology Triumphs.* A number of aging nuclear reactors are retired and subsequently decommissioned by electric utilities, but enhanced maintenance combines with successful life-extension programs to yield significant improvements in capacity factors at remaining plants. Successful R&D leads to the development of a new generation of smaller, passively-cooled reactors. A few utilities build on their historical success with conventional light-water reactors and construct new plants using these next-generation technologies at existing nuclear plant sites. Several states, eager to promote regional economic development and to gain the additional tax revenue associated with construction of new plants, encourage these efforts.

New Gadgets Increase Energy Demand, New Technologies Fuel Economic Expansion

In Technology Triumphs, *Americans become ever more enamored with electrical and electronic devices.* The resultant growth in demand for electricity, along with increasing demands for natural gas, characterize the *Technology Triumphs* scenario. Nonetheless, due to greater market penetration by energy efficiency systems and renewable energy technologies, energy demand and GHG emissions grow less rapidly than in *Awash in Oil and Gas.*

Both industrial and residential customers grow progressively more sensitive to issues of convenience, reliability, and quality of life. To ensure reliability, FERC requires the construction of a limited amount of new transmission infrastructure. But perhaps more important, the introduction of new information technology and solid state control electronics on both sides of the customer's meter aids local utilities in their efforts to maintain power quality and reliability. Time-of-day pricing is combined with these new control devices to give electricity consumers a clear idea of the value of their current demand and to offer scheduling options that defer non-critical demand during the utility's peak load periods.

U.S. consumers, industrial users, and retail businesses increasingly choose to invest in energy-efficient technologies rather than to buy power or energy services from traditional sources as the costs of the new technologies decline and approach those of conventional alternatives. Large industrial consumers, in particular, lead the market toward investments in efficiency and "green power." Customer preferences for the new technologies help to overcome or bypass the defensive responses of some historically dominant players in the U.S. energy market. New players enter the market whenever traditional actors are reluctant to meet customer demands.

Private investment in technology commercialization by U.S. companies becomes a principal driving force in *Technology Triumphs.* Early federal R&D investment enhances and facilitates this private investment. As energy and energy-related companies (including ESCOs) become more adept at matching their products and services to customer preferences, state-based policy initiatives successfully lower entrenched market barriers. Internationally, European governments encourage competitive technology investments by European companies through expanded R&D programs and targeted procurement agreements. These efforts lead to commercially successful European products that raise the competitive bar for U.S. companies and stimulate additional domestic R&D. Similarly, the Japanese government supports R&D by Japanese car companies on hybrid drive trains and fuel cell vehicles in order for these companies to compete more effectively with their U.S. competitors.

In this scenario, U.S. investors respond aggressively to these international initiatives and are willing to gamble on new energy technologies that carry both technical risks concerning their engineering performance as well as market risks related to consumer acceptance. Many U.S. investors believe that renewable energy, energy efficiency systems, and DG technologies can quickly become profitable, despite international competition. Investor optimism concerning the inherent advantages of these technologies in terms of smaller scale, reduced capital intensity, and the potential for economies of scale in manufacturing makes them a good bet.

In *Technology Triumphs,* sustained and patient efforts by U.S. investors lead to successful commercial deployment of efficiency-improving and carbon emissions-reducing technologies, including wind, solar, and biomass power, building-integrated photovoltaic (BIPV) power systems, hybrid gas-electric vehicles, and fuel cells. Japanese and European companies follow the U.S. lead in each major market segment, in many cases differentiating themselves from and improving upon U.S. products.

Around 2020, cost-reducing breakthroughs in solar photovoltaic (PV) module manufacturing and balance-of-system components allow PV systems to achieve widespread use in building-integrated applications. BIPV systems incorporate solar photovoltaic panels into the walls, windows, and roof structures of residential and commercial buildings. With the introduction of advanced, solid-state power control systems, structures employing BIPV installations can now be smoothly linked together into micro-grids capable of joint dispatch with conventional electricity supply technologies. Regional networks of BIPV micro-grids, which include small amounts of local energy storage, connect neighborhoods with complementary electricity load or solar insolation regimes increasing the value of the photovoltaics to the surrounding grid. The widespread introduction of BIPV systems and other renewable energy technologies, reinforced by expanded use of highly efficient, natural gas-fired combined cycle turbines offers multiple benefits in states like California, Florida, Arizona and Texas. The combination of environmental and reliability benefits of these distributed technologies, in conjunction with their declining costs, makes them increasingly attractive to both utilities and their customers.

Innovative approaches to the financial engineering of BIPV systems facilitate the creation of these networked micro-grids by allowing the photovoltaic cost to be rolled into mortgage financing and by recognizing the avoided cost of conventional architectural elements that are replaced by components of the BIPV system. BIPV systems and other distributed photovoltaic power applications earn credit for their reliability benefits, expected savings in transmission costs, and their ability to offset capital investments that would otherwise be required to reinforce existing elements of the transmission and distribution system. When their full value to utility distribution companies is recognized, micro-grid networks provide reliable power at retail costs competitive with electricity delivered from central-station natural gas or coal plants.

Growth of the associated energy industries helps to stimulate a modest domestic economic expansion in *Technology Triumphs.* Once commercialized in the United States, these new energy technologies ignite expansion of significant export markets. European and Japanese companies rush to replicate and improve on the recent American advances. The domestic and overseas demand for clean energy technologies gives a positive impulse to the manufacturing sector of the U.S. economy. Expanding exports (combined with declining demand for imported oil after 2010 and careful management of inflation by the Federal Reserve Board) help the economy to grow at an average rate of 3 percent per year during the scenario period.

Building Blocks of a Hydrogen Economy

Over the course of Technology Triumphs, *hydrogen becomes available for use in stationary and mobile fuel cell applications.* Between 2020 and 2035, the use of hydrogen as a fuel increases twenty-five fold. A number of different hydrogen production processes demonstrate engineering feasibility, allowing the production of hydrogen to take place at a variety of distances from the point of end-use: at filling stations, at buildings, and at remote, central-station facilities. Some of the production processes are based on the breakdown of fossil-fuel feedstocks. Others rely on renewable energy technologies for the electrolysis of water. By 2035, gasification of coal, with conversion of the resultant syngas to a hydrogen-rich fuel-gas, has become cost-effective. The hydrogen-rich fuel-gas is burned in high-efficiency, combined-cycle turbines or used in fuel cells to produce electricity. Purified hydrogen is also produced in dedicated facilities for use as a transportation fuel and as a feedstock for petrochemical refineries.

Declining costs of advanced solar and wind electric systems stimulate commercial production of hydrogen through water electrolysis toward the end of the scenario. In the Great Plains, steady winds and the availability of land contribute to the installation of significant numbers of economically competitive, central-station wind farms. But most of the best wind sites are far from traditional electric load centers. The hydrogen is piped to city-gate distribution centers in metropolitan areas throughout the Midwest.

Successful development of regional infrastructures for hydrogen transport and distribution significantly reduces public fears concerning the safety aspects of hydrogen supply and use. By 2035, public-private partnerships have developed regional infrastructures for hydrogen production, storage, and distribution in many regions of the United States, particularly in the West, Southwest, Midwest, and Appalachia.

New Towns, New Vehicles, New Fuels

Motor vehicle manufacturers respond to new air quality and CO_2 regulations in California and other states by accelerating production of hybrid cars, advanced ICEs (including both diesel and gasoline engines), and fuel cell vehicles. By 2005, hybrid gas-electric and diesel-electric vehicles are a success in the California car market. The highly visible success of hybrid cars in the California market along with concerns in other states about local air pollution stimulate a nationwide push for extremely low-emission vehicles. The impetus created by the federal FreedomCAR and hydrogen initiatives, as well as the California Fuel Cell Collaborative, assist in meeting this demand. These public-private partnerships accelerate the development of fuel cell cars and light trucks, as well as hydrogen production and distribution.

Fuel demand for personal mobility changes dramatically in *Technology Triumphs.* Individual desires to avoid congestion reinforce state policies to promote urban in-fill and encourage local initiatives to discourage suburban sprawl. These initiatives reinforce emerging trends, resulting in citizens migrating to edge cities where jobs and housing are located near family recreation. This transition stimulates the market for city cars and further expands the demand for hybrid vehicles from 2005 to 2020.

Fuel cell and hybrid vehicles capture a substantial and growing share of the city car, family car, and light truck market segments nationwide. Demand for hybrid cars and light trucks begins to take off nationwide, reaching approximately 3.9 million vehicles by 2015, representing 20 percent of new light-duty vehicle sales.

Fuel-cell cars using pure hydrogen achieve early market penetration. Vehicles employing proton-exchange membrane fuel cells (PEM-FCs) are first demonstrated in California in 2005. By 2015, fuel cell vehicles capture approximately 2.5 percent of new light-duty vehicle sales, or approximately 480,000 units. Pure hydrogen is widely available by 2020 as a transportation fuel. This gaseous hydrogen is produced using a variety of processes and is distributed through a wide range of outlets. Decentralized production and distribution of hydrogen from gasoline or natural gas at fueling stations is available in some regions. By 2020, fuel cell vehicle sales exceed 5 percent of the light-duty vehicle market, and by 2035 fuel cell vehicle sales reach almost 3.9 million vehicles per year in *Technology Triumphs,* capturing approximately 20 percent of light-duty vehicles sales in the United States. Concurrently, some trucking fleets begin to experiment with hydrogen and fuel cell powered vehicles.

Bio-fuels expand their penetration into the transportation market midway through *Technology Triumphs.* Following new guidelines from the World Trade Organization (WTO), federal policy encourages farmers to grow bio-energy crops for liquid fuels, and new agricultural support programs encourage bio-fuels production. Beginning in 2015, light trucks start shifting to clean diesel, including bio-diesel, as their primary fuel, requiring advanced emissions control technologies to meet the 2015 standards for NO_x and other air pollutant emissions.

Railroads and mixed mode freight systems capture a growing share of freight tonnage in *Technology Triumphs*. Private investment in new freight handling facilities coordinates well with federal and state support for rail track enhancements and new port facilities, increasing the overall efficiency of freight transport. For some industries, these new facilities accelerate the movement of goods from the factory floor to the assembly plant or distribution warehouse, enable just-in-time manufacturing strategies, and lower inventory holding costs. For others, new integrated, mixed-mode delivery systems track millions of orders and deliver the goods overnight, directly to the consumer's door.

Smart Houses Waste Little Energy

Both residential and commercial buildings are affected by state initiatives promoting energy efficiency-improving and carbon emissions-reducing technologies. In 2005, Microsoft incorporates "SmartHouse" software into its new personal computer operating system, *Windows XP Home 2005.* The new operating system connects to a new family of sensors and controls that are retrofitted to the power plug for existing appliances, lights, and other devices. These sensors and controls allow home computers to monitor and control electricity use by all appliances and lights in the house as well as to control the heating, ventilating, and air conditioning systems. By 2010, personal computers manage energy use in approximately 20 percent of U.S. homes. Computer control of gadgets and appliances is especially important in reducing household energy waste, especially the silent standby "vampire" loads generated by alarm systems, cable-TV converter boxes, and remote control devices for stereos, lights, and TVs, which draw energy even when turned off. Similar systems are used to reduce electricity use by lights, ventilation, and office equipment in commercial buildings.

Beginning in 2005, federal mortgage lending support programs underwrite interest rate reductions for homebuyers and builders who include the full cost of DG systems, renewable energy generation, and energy efficiency improvements in conventional home mortgage loans. (These are some of the same programs identified earlier as supports for the development of neighborhood micro-grids.) This mortgage-based lending strategy rapidly accelerates the uptake of BIPV systems, DG technologies, and energy efficiency measures into residential markets.

For example, annual installations of BIPV increase by about 25 percent per year, reaching approximately 1,225,000 residential BIPV systems, each with an average system size of 10 kW (peak) by 2035. During the same period, the number of annual installations of commercial BIPV systems grows by about 18 percent per year, to a rate of approximately 2,350 commercial buildings per year, each with average system size of 5 MW (peak). Thus, the installed base of BIPV systems is capable of producing about 136 GW (peak) in 2035, with about 45 percent of the installed capacity in the residential sector and 55 percent in the commercial sector. Taken together, residential and commercial BIPV systems generate approximately 240 TWh per year in 2035, equivalent to approximately 4 percent of total electricity production.

The spread of inexpensive, broadband communications into the residential sector encourages many workers to telecommute from home. By 2010, more than 10 percent of the U.S. workforce operates from home at least one day per week, reducing vehicle miles traveled, congestion, and excessive engine idling in traffic. Telecommuting also encourages increased demand for new computers, software, and telecommunications services.

NIMBY Complicates Planning for All

Local resistance to construction of new facilities (including transmission lines and pipelines) complicates planning for energy projects in Technology Triumphs. Neighborhood concerns about quality of life issues (NIMBY) act to limit siting of technologies that are generally considered dirty. The extent of local resistance varies by technology and by region.

States use their authority over siting decisions to promote clean technologies. The new state siting standards increase the challenges of licensing many conventional energy facilities.

Customer concerns about generation system reliability, electric power quality, and air pollution lead to expanding investments in energy efficiency and on-site CHP facilities in *Technology Triumphs.* Faced with the highly competitive energy market in this scenario, corporate procurement officers reflect customer values in their energy purchasing decisions. Both individual consumers and private firms consistently show a willingness to pay modest price premiums in *Technology Triumphs* for energy technologies and for energy services that are convenient, reliable, and viewed as clean.

Summary

In Technology Triumphs, *the U.S. energy sector develops a broad and diverse portfolio of advanced energy supply and end-use technologies.* The U.S. economy expands steadily. Key factors contributing to economic growth include a strong foundation of energy efficiency-improving technologies, reliance on continental fuel resources, expanded use of renewable energy supplies, accelerated commercialization of DG, and the export of clean technologies. The balance of investment in the electricity sector shifts to natural gas, DG, and renewable energy technologies. In the transportation sector, the trend of annual purchases of new light-duty vehicles moves strongly toward hybrid gas-electric and diesel-electric vehicles, advanced internal combustion engines, and fuel cell powered cars. Railroads and mixed mode freight systems capture a growing share of freight tonnage. Heavy trucks begin to experiment with hydrogen and fuel cell powered vehicles. However, significant population growth, rising GDP, and increasing demand for electricity more than offset the impacts of advanced efficiency-improving and carbon emissions-reducing technologies, causing U.S. CO_2 emissions to increase. By 2035, CO_2 emissions are approximately 15 percent above the 2000 level.

Table 2

Timeline for **Technology Triumphs** Base Case

2005	• States mandate interconnect standards and common tariff policies for distributed generation • Hybrid gas-electric vehicles and advanced internal combustion engines become a commercial success in the U.S. market • Microsoft introduces "SmartHouse" software in MS Windows XP Home 2005
2010	• 10 percent of U.S. workforce telecommutes at least one day per week • 20 percent of U.S. homes have computer-based energy management systems • CHP systems provide electricity equivalent to 13 percent of the increase in electricity demand since 2000
2015	• FreedomCAR Initiative leads to cost-effective fuel cell vehicle employing PEMFCs • California Fuel Cell Collaborative delivers cost-effective stationary fuel cells • National interconnect standards facilitate introduction of DG systems on a nationwide basis
2020	• Solar photovoltaic power systems are cost-competitive in a wide variety of markets and applications • Natural gas and bio-fuels are used in commercial fuel cells • Sales of pure hydrogen fuel cell cars with on-board hydrogen storage reach 5 percent of new car sales • Fuel cells coupled to microturbines are introduced in CHP applications
2035	• Regional infrastructures for hydrogen production, storage, and distribution are in place in the West, Midwest, Southwest, and Appalachia

C. Turbulent World

Overview

Turbulent World *is an event-driven scenario, characterized by severe stresses and broad challenges.* It is a confusing and chaotic world, where several parallel story lines play out. Constant dislocations, ubiquitous conflicts, and historically low levels of global cooperation shake the U.S. economy and disrupt the energy sector. Price spikes and supply disruptions in the energy sector combine with terrorist incidents, accidents, and domestic weather-related disasters to unsettle the confidence of U.S. investors and consumers in large-scale, conventional, centralized technologies. High prices for fuels and electricity along with considerable uncertainty about future investment conditions slow economic growth in *Turbulent World.* In this slowly growing economy, U.S. carbon emissions rise to 15 percent above their 2000 level in 2010, and slowly grow to almost 20 percent above the 2000 level in 2035. U.S. policymakers are buffeted by external events they cannot control and by wide swings in popular perceptions that they are unable to moderate. The principal driving force for policy is concern about energy security. The emphasis of domestic energy policy shifts abruptly from one technology to another, but one by one, each "solution" is revealed to have a major flaw. There is one exception: to reduce dependence on imported oil, the federal government initiates a "crash" program designed to accelerate the commercialization of fuel cells that burn hydrogen derived from coal. This program, implemented on the scale of the Apollo "moonshot," proves successful.

Profound Political Forces Disrupt the International Oil Market and Lower U.S. Oil Consumption

Outside the United States, nationalistic and geopolitical forces undermine stability in several important oil-producing states. Venezuela loses half of its export capacity due to conflicts between a populist government and an entrenched management bureaucracy. Iraq is invaded by an international coalition, with the next ten years spent rehabilitating and modernizing Iraqi oil fields. Fundamentalist challenges to reigning national governments lead to major economic and political dislocations on both sides of the Persian Gulf. Hostility to U.S. presence in the region and to sustained U.S. support for Israel continues to grow during 2000 to 2010. Political challenges to regimes in Saudi Arabia, Kuwait, and the United Arab Emirates boil over, with major disruptions of petroleum output occurring from 2005 to 2010. The Organization of the Petroleum Exporting Countries (OPEC) cannot moderate these disruptions through changes in the world oil price.

The resulting series of price shocks and supply interruptions culminates in 2010 with fundamentalist radicals overthrowing the House of Al-Saud, destroying the production infrastructure in the Eastern Provinces of Saudi Arabia, and torching large oil shipping terminals in the Gulf. A wave of attacks on oil tankers in the Gulf and sporadic terrorist attacks on energy facilities within the United States follow the fall of the Saudi regime. These events lead to a series of price spikes and a major disruption of oil supply. As a consequence, world oil prices more than double from year-2000 levels by 2010.

Early on in *Turbulent World,* a series of Russian governments attempts to reform and modernize the national oil and gas sectors. The disruptions in Middle East production occur before these reforms can fully take effect and before major, on-going private investment programs can sufficiently increase exports of Caspian Sea oil to compensate for reductions in Middle East oil exports. Although efforts to develop major new oil resources continue in areas offshore of Brazil, southern Vietnam, and Angola, none of these off-shore fields comes on-stream in amounts large enough to replace the Middle Eastern oil exports that were cut off in 2010.

Beginning in 2005, U.S. policymakers become extremely sensitive to issues of energy security, focusing simultaneously on risks to individual facilities and on growing U.S. dependence on foreign oil that is exported from politically unstable regions. The United States views itself as the sole remaining superpower and guardian of the world's sea lanes. Public perceptions focus on high gasoline prices and on the continuing insecurity of imported oil supplies. In *Turbulent World,* this focus on energy security creates an urgent national priority to protect critical energy facilities. Diplomatically and militarily, the United States seeks to prevent any credible threat to the stability of oil supply and to the shipping lanes through which oil must pass. In the first decade of *Turbulent World,* environmental concerns remain low on the U.S. policy agenda, seemingly far less urgent than issues related to defense, national security, or the domestic economy.

From 2010 to 2015, in the wake of the fall of the House of Al-Saud, radical and repressive, fundamentalist regimes emerge in the oil emirates of the Middle East and the former Soviet Republics of Central Asia. Following the example of the Taliban in Afghanistan, these anti-Western regimes focus inward, shunning trade relations with the West. Oil exports from the Middle East to the United States remain limited and unreliable. Also during this period, however, most non-OPEC producers increase their output to maximum levels, and new Russian, Brazilian, and African production comes on-stream. Oil prices (measured in constant dollars) remain volatile, but begin to decline from the peak levels of 2010. By 2020, average world oil prices decrease to about 70 percent above the year-2000 level. During the next fifteen years, they continue declining, but by 2035, they are still 50 percent higher than in 2000. High oil prices suppress oil demand in the United States. Oil use in the industrial sector declines. Oil demand for transportation rises more slowly than the historical trend. Overall, aggregate U.S. oil consumption falls to 85 percent of year-2000 levels by 2035. However, imports are still required to meet almost 60 percent of U.S. demand for petroleum in 2035.

By 2030, several of the new fundamentalist regimes in the Middle East have given way to nationalistic, moderate, mercantilist states that are intent on re-entering the world economy and dominating worldwide oil and gas trading. These new regimes appear less hostile to U.S. interests. Nonetheless, U.S. policymakers and the general public believe that U.S. energy security is threatened by continued dependence on oil imports from these traditionally insecure regions. Several leading politicians argue that America should intervene in the remaining fundamentalist regimes to protect the interests of the United States and our allies in the global economy. Others suggest that consistent implementation of the doctrine of preemption, now a staple of U.S. foreign policy, would urge the United States to intervene in these countries if only because they may become a future threat to U.S. national interests. Despite repeated threats, no additional invasions occur during the course of *Turbulent World*.

Extreme Weather and Unexpected Events Erode Public Confidence In Centralized Technologies

While the events described above unfold internationally, a number of unexpected events occur domestically that, taken together, combine to erode public confidence in conventional, highly centralized technologies. In 2010, a terrorist incident at a U.S. nuclear power plant causes federal regulators to require stringent new security measures to protect the entire nuclear fuel cycle, significantly increasing operating costs for all nuclear facilities. But even these new measures are insufficient to allay public fears. The incident dramatically elevates public concerns about the risks of commercial nuclear power and, combined with lingering public fears about incomplete federal plans for the transport of radioactive waste, leads to rising public resistance to the construction of any new nuclear power plants.

Public concerns about the cost of nuclear accidents and terrorist incidents spark a spirited debate in the U.S. Senate and lead ultimately to rejection by Congress of the president’s proposed re-authorization of the Price-Anderson Act (the principal mechanism for capping risk exposure for U.S.

nuclear facilities). The cost of measures for ensuring facility security, combined with the elimination of federally subsidized insurance for nuclear plants, make it virtually impossible for any company to finance new construction of either conventional or advanced nuclear facilities after 2010. Nuclear plant operators hold on to their assets and continue to operate them despite public protests, seeking the maximum possible life extension for existing licensed facilities.

Unusually hot, dry summers in 2010 to 2012 and a severe drought during the same period create peak power shortages and water emergencies in the hydro-dominated electricity systems of California, Oregon, and Washington. In 2012, the return of a second successive severe El Niño causes a recurrence of the 500-year floods throughout the Red, Mississippi, and Missouri River valleys, events last experienced during the historic floods of 1993. Most American adults feel that the weather has changed dramatically from what they remember as children growing up. Some scientists continue to argue the point, but the general public grows convinced that the increasing frequency of extreme weather events is a reliable indicator of long-term climate change. In 2013, the prospect of another West Coast summer power crisis impels the federal government to re-evaluate the longer-term challenges of electric power supply, distribution, and use.

A severe regional ice storm in the spring of 2015 causes simultaneous failures at three major junctions of the East Coast high-voltage transmission system and creates a four-day blackout from Boston, MA, to Charlotte, NC. Development of frontier North American gas fields continues until the summer of 2015 when a major pipeline accident and subsequent explosion shut down the Alaskan Gas Pipeline. These events combine with the memory of the nuclear power plant incident five years earlier to drain public support from large, centralized energy production and distribution schemes, and to build public support for the development of DG and other decentralized technologies.

By December 2015, there is a general sense of malaise and lack of direction or strategic vision throughout the country. Most people sense constant threats and pervasive external disorder. Citizen resistance and concerns about energy facility security makes it difficult, contentious, and expensive to build large, new, or unfamiliar facilities in most parts of the country. Critics of new projects often mount populist campaigns based on NIMBY arguments. Commercialization of new technologies is slowed by the difficulties encountered in siting new plants, whether these plants expose the surrounding communities to danger or not. Affected projects include advanced nuclear plants, hydrogen fueling stations, coal gasification plants, and electricity transmission lines.

In this environment, the federal government seeks an energy strategy that is technically feasible, economically attractive, and does not depend on the whims of foreign governments or the vagaries of the weather. But the emphasis of U.S. energy policy shifts abruptly from one technological “solution” to another throughout *Turbulent World.* And one-by-one, each anointed technology under-performs the claims made for it by its most ardent supporters. Each successive failure lowers public confidence in the idea that the United States can manage complex technological undertakings successfully.

Trying to Power Up with Domestic Resources

Early in this scenario, U.S. energy policy focuses on expanding domestic energy supply based on conventional fuels and advanced technologies, especially nuclear power and coal. Private and public investment in advanced nuclear technologies leads to major engineering successes in the first decade of *Turbulent World.* A big push on R&D and accelerated commercial deployment beginning in 2005 brings the prospect of accident-resistant nuclear power technologies tantalizingly close. From 2000 to 2010, output from U.S. nuclear plants increases by approximately three percent, as plant operators improve performance at existing facilities and the first units of a new generation of smaller, passively-cooled reactor designs comes on line. Nonetheless, public acceptance of nuclear technology remains problematic. Existing plants are re-licensed, but issues of perceived financial risk keep U.S. utilities from building many new plants. Following the terrorist incident at a U.S. nuclear plant, the subsequent imposition of a stringent security regime at all nuclear facilities, and the expiration of the Price-Anderson Act in 2010, the domestic market for advanced reactors shrivels up. Nuclear plant output declines overall, falling to approximately 95 percent of 2000 levels by 2035. Many first generation reactors are decommissioned, and only the additional plants that were under construction in 2010 are brought on stream as replacements.

From 2010 to 2020, U.S. energy policy seeks to increase electricity generation from coal because of its domestic availability, its low resource cost, and the proximity of low-sulfur Western coals to the fast-growing Intermountain and Pacific Coast markets. But rising local concerns about air pollution increase the resistance of communities to siting new plants. This occurs despite a new round of nationwide reductions in air pollution from fossil fuel-fired power plants.

A national RPS is incorporated into the National Energy Policy Act of 2012. It provides a significant commercial impetus for solar, wind, and biomass systems, but the market penetration of these technologies continues to be relatively modest in *Turbulent World.* In 2012, biomass energy systems demonstrate cost-effective operation in many regions of the country. However, high transport costs for biomass feedstocks limit their use, making biomass technology strictly a regional solution. In aggregate, bio-energy systems contribute approximately one Quad of primary energy in 2035. Nonetheless, in the wake of the new RPS requirements, non-hydro renewable energy technologies are able to supply a total of 13 percent of U.S. electricity generation by 2035.

As public concerns rise regarding the security of nuclear facilities, the safety of transporting high-level nuclear waste around the country, the air pollution from coal combustion, and the limited regional nature of biomass resources, the federal government launches a “moonshot” crash program to produce fuel cells powered by hydrogen from coal. By 2015, high-temperature fuel cells combined with micro-turbines become a technology of choice for commercial- and industrial-scale CHP facilities. In the residential, commercial, and industrial sectors, new national standards for appliance efficiency, lighting, and the energy performance of buildings lead to the commercialization of a broad range of energy efficiency systems. Simultaneously, renewable energy technologies and energy efficiency systems receive a boost in *Turbulent World,* as many in the U.S. seek to do "something, anything" to increase reliance on domestic resources.

Distributed generating technologies appear first in commercial cogeneration applications, and then in residential applications in upscale, gated communities. Cogeneration technologies achieve widespread commercial acceptance in a variety of CHP applications. National interconnection standards and national tariff policies are agreed to in 2010, giving a dramatic boost to DG technologies and renewable energy systems. Transparency in pricing leads to a more complete valuation of the contribution that DG systems make to the operations of the distribution grid. As new valuation techniques for DG systems come into wider use and the contributions of these technologies to system reliability, power quality, and the ability to defer capital investment become more apparent, the electricity that is produced by DG systems rapidly becomes cost competitive with electricity from central station plants sold on the wholesale market.

Research on IGCC (including those equipped with carbon capture and sequestration technology) succeeds in reducing their cost and improving their performance. In *Turbulent World,* public confidence in the safety of IGCC facilities remains higher than confidence in the expansion of continental-scale natural gas pipelines since most people believe that the risks associated with these coal plants are less significant than the risks of explosions or terrorist attacks associated with natural pipelines and terminals. By 2020, IGCC technology has achieved commercial success in the U.S. electricity sector, taking market share from all other conventional generating technologies and capturing almost 15 percent of coal-fired generation in 2035.

Despite the chaotic character of the early years of *Turbulent World,* some trends continue. Population grows by 20 percent from 2000 to 2035. End-use electricity demand grows by about 60 percent. High prices for fuels and electricity along with considerable uncertainty about future investment conditions slow economic growth, relative to the two other base case scenarios. Economic activity increases at an average annual rate of 2.4 percent.

On the Road with New Cars and Trucks

The growing demand for big, muscular vehicles leads to steadily increasing oil imports in the early years of Turbulent World*.* In 2010, with U.S. oil imports up about 15 percent from year-2000 levels, and after years of frequent oil supply disruptions and price spikes, the pressure of public opinion forces the U.S. administration to implement policies that would systematically reduce oil import dependence. In the short term, these policies focus on the transportation sector. In 2010, new passenger car Corporate Average Fuel Economy (CAFE) standards are announced that raise the CAFE standard for the combined passenger car, minivan, and light-duty truck fleet to 32 mpg in 2015 and 50 mpg in 2020.

Amidst rising concern about U.S. oil import dependence, the federal government "moonshot" program welds together a coalition of university researchers and private technology developers with the goal of producing one million fuel cell powered cars annually by 2025, at prices competitive with conventional vehicles using internal combustion engines. By 2020, that target is substantially exceeded.

The moonshot also includes a decade-long program to develop and commercialize hydrogen fuel in a wide variety of applications, including both vehicles and power applications. Federal R&D investment in a range of approaches to centralized production and distribution of hydrogen stimulates the production of hydrogen from coal. Federal tax policy begins subsidizing hydrogen production and provides accelerated depreciation for investments in hydrogen pipelines, pumping stations, and local distribution stations. In addition, a portfolio of tax incentives and other policies is implemented to promote alternative fuels and electric power trains for light-duty vehicles. The new policies converge with the new CAFE standards to accelerate the commercial deployment of hybrid gas-electric and diesel-electric vehicles, direct injection diesels, lean-burn internal combustion engines (ICEs), and fuel cell powered vehicles.

By 2030, the United States has begun to reduce its dependence on imports of foreign oil. The programs to promote hydrogen fuel and fuel cell technology, increase CAFE standards, and promote energy efficiency all move toward reducing oil demand, especially in the transportation sector. The bulk of hydrogen production in this scenario is from coal, coupled with IGCC technology and geological sequestration. The rapid deployment of this technology is the most visible benefit of the federal program promoting hydrogen fuel technology.

A Place to Put Carbon

Throughout Turbulent World, *an extended series of extreme weather events raises public concern about the risks of climate change due to the greenhouse effect.* As a hedge against potential climate risks, in 2010 the president initiates a National Academy of Sciences (NAS) study of technologies for carbon sequestration in geologic formations.

In 2012, the NAS completes its study of carbon sequestration, concluding that CO_2 can be safely and permanently sequestered in underground brine-filled reservoirs with secure top covers, even those that are not completely sealed. The results of the NAS study reinforce other sources of political pressure to increase reliance on domestic energy resources and reduce oil import dependence. As a consequence, federal energy policy encourages a rapid increase in both public and private R&D on carbon sequestration technology.

In *Turbulent World,* many analysts argue that expanded use of DG will improve the reliability of the U.S. electricity system and provide significant security benefits. From 2012 onwards, federal policy places increasing emphasis on the commercialization of DG technologies and on developing advanced coal combustion technology (coupled with carbon sequestration in geological formations).

The role of IGCC plants that burn regional coal (as well as local biomass) grows rapidly in *Turbulent World.* Substantial R&D investment early in the scenario leads in 2010 to the first commercial demonstrations of carbon capture and sequestration in conjunction with hydrogen production at IGCC plants.

Summary

Turbulent World is an event-driven scenario characterized by shocks, disruptions, and failed expectations about the potential of energy technologies to address societal challenges. It is a scenario with several parallel story lines in which U.S. policymakers are buffeted by external events they cannot control and popular perceptions that they cannot moderate. U.S. energy policy first latches onto one technological solution then another, only to discover that each new solution has a crippling problem. The United States becomes a society in which "muddling through" seems to be the only available option but not one where consumers or national policymakers have confidence in the outcome. The one exception is the crash "moonshot" program to develop and commercialize fuel cell and hydrogen technologies. By 2035, IGCC and DG have achieved widespread commercial success, fuel cells become an important part of the U.S. energy portfolio, and non-hydro renewable energy technologies supply approximately 10 percent of U.S. electricity.

Table 3

Timeline for Turbulent World Base Case

2005-2010	• U.S. energy policy focuses on import dependence and domestic resources, including the development of a new generation of nuclear power plants
2010	• After several years of major disruptions, radical fundamentalists overthrow the government of Saudi Arabia • World oil prices are more than double their year 2000 level • Terrorist incident at nuclear power plant undermines citizen confidence in commercial nuclear power • United States decides to act on energy • Federal government initiates "moonshot" program of fuel cell and hydrogen development
2010-2015	• Floods, droughts, and hot spells disrupt the U.S. economy • Ice storms and other extreme weather events occur throughout the country • Nuclear and distributed generation options reconsidered • First commercial demonstration of CO_2 capture and sequestration
2020	• IGCC achieves commercial success • DG becomes a status item in gated communities • CAFE standards reset to 50 mpg • Over one million fuel cell powered vehicles produced annually
2035	• World oil prices are still 50 percent above year 2000 level • CO_2 emissions from electricity generation increase by 35 percent from year 2000 levels • Carbon emissions from vehicles decline despite 50% increase in VMT from 2000 to 2035, mainly due to sales of advanced ICEs, hybrid electric vehicles, and fuel cell vehicles • Non-hydro renewable energy technologies contribute over 10 percent of U.S. electricity supply

III. Implications

A. Overview

Each of the scenarios presented above describes a plausible trajectory for the United States, but none is a prediction of the future. Each illustrates a different path of development for the energy supply sector, and each reflects a distinct pattern of decision making about energy consumption and investment by consumers, government, and businesses.

A comparison of these widely divergent scenarios reveals key technologies, policies, and investment patterns that are likely to support the goals of sustaining U.S. economic development, reducing the impact of U.S. energy use on the global climate, and improving U.S. energy security across this wide range of possible futures. The most important technologies include fuel cells, IGCC power generation, geological carbon sequestration, energy efficiency systems, renewable energy, hydrogen production, and hybrid-electric vehicles. The commercialization of these technologies in the Pew Center scenarios is facilitated and accelerated to varying extents by key policies, strategies, and investments, including fuel economy and air quality requirements, interconnection standards, and aggressive investment in and development of the infrastructure required for widespread production and delivery of hydrogen as a fuel. These implications are discussed in more detail below.

These technologies (see Box 1), policies, strategies, and investments were identified through discussions with the business, research, NGO, and other experts who participated in the scenario-building process. In addition, the AMIGA model was used to provide an illustrative quantification of each scenario and to analyze them in a consistent framework. The AMIGA model was selected because of its detailed representation of energy supply and demand, its extensive database on energy-using capital stock in the economy, and its ability to incorporate different technology performance and cost characteristics. The AMIGA model is able to estimate future carbon emissions, GDP, energy use, and investment patterns as a function of assumed policies, technology cost and performance, resource levels, and price trajectories for energy and other commodities.

See Box 2, and Appendix D (in the web-based version of this report), for a more detailed description of the AMIGA model.

B. The Policy Overlay

Climate change policy was deliberately excluded from the "base case" scenarios. In order to explore the possibilities of reducing U.S. carbon emissions in each of the scenarios, a hypothetical suite of emissions control policies (the policy overlay) was identified. Implementation of these policies was simulated using the AMIGA model. The policy overlay was designed to freeze U.S. CO_2 emissions from fossil fuel use in 2010, to initiate a steady decline of 2 percent per year in those emissions from 2010 to 2025, and to accelerate the rate of decline in average annual CO_2 emissions to 3 percent per year from 2025 to 2035. This trajectory results in U.S. emissions in 2035 that are approximately 38 percent below the year-2000 level. This overall emissions reduction trajectory was selected because it is consistent with the reports of the Intergovernmental Panel on Climate Change and other scientific authorities suggesting that U.S. GHG emissions must decline by at least 70 percent by the end of this century to contribute proportionately to worldwide efforts to stabilize global concentrations of greenhouse gases at a relatively stringent level. The participants in this scenario exercise did not discuss how a national decision to impose this type of cap on U.S. carbon emissions might be made, only the extent and the rate of emissions reductions.

The policy overlay included market-based and other mechanisms as tools for accelerating the introduction of new, more efficient, and less carbon-intensive technologies while meeting future demands for energy services. A portfolio of policies was introduced in the model to stimulate investment, accelerate capital stock turnover, and encourage emissions reductions. These policies affect all sectors of the economy but have the greatest impacts in the energy supply sector and in those sectors of the economy with the largest energy demand. The portfolio of policies includes:

- Performance-based CO_2 and efficiency standards applied to the transportation sector, implemented through tradable emissions credits;
- Incentives to accelerate research and development of new low-carbon and energy-efficient technologies through innovative public-private partnerships;
- A downstream carbon emissions allowance cap-and-trade program applied to the electricity generation and industrial sectors of the economy;
- Investment and production tax credits for efficiency-improving and carbon emissions-reducing technologies; and
- A set of "barrier busting" programs designed to reduce market imperfections and promote economically-efficient decision-making by individual consumers, investors, and institutions.

For details on the policies simulated with the AMIGA model, see Box 3.

This policy overlay was used as an analytical tool to explore the costs and feasibility of reducing carbon emissions from energy production and use. It was limited to measures that could reduce U.S. domestic CO_2 emissions because the scope of this project was limited to U.S. energy production and use.

Box 1

Technology Assessments

Several technologies, currently in various stages of development, have the potential to radically transform future U.S. energy supply and demand. In support of the scenario planning exercise, the Pew Center and GBN produced technology assessments of six key technologies: geological carbon sequestration, fuel cells, hydrogen, energy efficiency, advanced nuclear technologies, and distributed generation. The technologies are assessed in terms of their technical characteristics, environmental attributes, energy security implications, expected timing and availability, costs, key uncertainties, and issues affecting deployment. The role of the technologies in the Pew Center scenarios is also discussed. The technology assessments can be found in the longer version of this report that appears at www.pewclimate.org.

Geological sequestration is the long-term storage of CO_2 in underground reservoirs. Currently, CO_2 from large stationary sources is captured and injected into geological reservoirs in limited commercial applications. Use of long-term, large-scale storage would require improved knowledge of reservoirs and overcoming economic and technological challenges. If large-scale use proves feasible, it could enable continued use of fossil fuels while greatly reducing CO_2 emissions.

Fuel cells combine hydrogen and oxygen to generate electricity, water, and heat. Stationary fuel cells can generate electricity and heat for industrial processes, and mobile fuel cells can power vehicles. Fuel cells offer significant efficiency and environmental benefits but face challenges including high cost, hydrogen availability, and structural barriers of the electric utility sector.

Hydrogen is a possible zero-carbon substitute for fossil fuels. There are major technical, economic, and institutional challenges associated with significantly expanding the role of hydrogen in energy markets, including having to create or adapt the physical infrastructure necessary to distribute and store hydrogen.

Advanced nuclear technologies includes a variety of advanced power technologies that may offer lower costs and increased security compared to conventional nuclear power. All offer major carbon benefits over fossil fuels. The risks associated with these technologies are not yet fully quantified and they face many technical, economic, and institutional challenges.

Energy efficiency technologies significantly reduce the amount of coal, oil, gas, or electricity that is required to achieve a given level of energy service or economic benefit. The technical potential of energy efficiency technologies is indisputable but their economic potential varies, and they face many market barriers.

Distributed generation (DG) is modular electric generation located close to the point of use, allowing for combined heat and power production. Many promising distributed generation technologies are available, but the current electric generation and distribution system is not well positioned to take advantage of them.

The policy overlay described in this report does not represent a set of policy recommendations by the Pew Center or the participants in the scenario planning exercise. In fact, the Pew Center advocates a broader approach to climate change policy, an approach that goes beyond initiatives affecting U.S. energy consumption and incorporates measures to promote carbon sequestration in soils, forests, and vegetation; international emissions trading; and initiatives to reduce emissions of greenhouse gases other than CO_2. A series of reports published by the Pew Center and others suggests that inclusion of this broader range of options would substantially reduce the burden on the U.S. energy sector.[13]

For example, many analysts argue that if the United States recognized international purchases of GHG emissions reductions (or emissions allowances) as offsets to domestic carbon emissions, the cost of these purchased offsets could be substantially less than the cost to the U.S. energy industry of mitigating

Box 2

Quantifying the Scenarios

The AMIGA model, developed by the U.S. Department of Energy's Argonne National Laboratory, is a multi-sectoral simulation model of the U.S. economy. The model contains a detailed representation of the building, industry, transportation, and electricity sectors of the U.S. economy, including a database representing the installed capital stock in the transportation, electricity, and buildings sectors. Built around a series of behavioral equations concerning the acquisition, deployment, and retirement of energy-using capital stock in each sector, the model estimates the demand for energy services by sector and across the economy as a whole.

The AMIGA model uses a set of equations describing the competitive behavior of U.S. energy markets, including consideration of resource costs, capital and operating costs of existing plants, policies (including carbon cap and trade programs or efficiency standards), and the performance and cost characteristics of specific facilities or typical technologies to simulate the supply of primary energy and electricity. The model iterates between estimates of energy demand and energy supply in each benchmark year to produce an internally consistent set of market-clearing prices. Iterations continue until the energy markets are in equilibrium between supply and demand. At this point, the model calculates various indicators of economic performance, including personal consumption, private investment, net imports, and public spending. These components are aggregated into Gross Domestic Product (GDP). In addition, the model calculates primary energy demand by sector and fuel; electricity production by fuel and technology; new vehicle purchases in each market segment; as well as estimated emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and mercury (Hg).

For each of the Pew Center base case scenarios, parameters such as the rate of growth in economic activity, technology cost and performance characteristics, and fuel supply and demand curves were specified to be consistent with the scenario narratives. The Pew Center's policy overlay cases were constructed by imposing the portfolio of policies described in detail in Box 3 on the three base case scenarios. In each of the three policy overlay cases, the AMIGA model was used to estimate the level and composition of economic activity (i.e., both the aggregate GDP and its principal components) before the behavior of the energy markets was simulated.

In each of the base case scenarios and the policy overlay cases, the transportation and electricity sectors were given special attention because of the size of their contributions to U.S. carbon emissions. Special efforts were made in this study to test the potential for reducing emissions from light-duty vehicles. To explore this potential, the AMIGA model was used to track the capital stock of light-duty vehicles (separately from heavy trucks and buses); the model allowed that capital stock to accumulate new vehicles through purchases and retirements on a year-by-year basis. In the electricity sector, AMIGA simulated the annual retirements of existing U.S. power plants, based on a complete vintaged database. As plants retired, and new electricity demand emerged, the model selected the least-cost expansion plan from among more than two dozen types of new generation technologies, including advanced fossil fuel technologies, renewable energy technologies, advanced nuclear power plants, natural gas-fired turbines, integrated gasification and combined cycle turbines, and combined heat and power plants.

For the purposes of this analysis, the AMIGA model was modified to evaluate the effects of a carbon cap and emission allowance trading system on the capital stock of electric power plants in the United States. Additional analytic modules were added to the model to evaluate the impacts of targeted federal spending programs as well as to improve its ability to simulate the effects of energy efficiency initiatives on the residential, commercial, and industrial sectors.

The starting point for the AMIGA model inputs was the EIA's Annual Energy Outlook 2002 reference case.[18] These reference case inputs were adjusted for each scenario according to the specific characteristics of that scenario. The first key input category for the scenarios is fossil fuel prices. Oil prices are specified throughout the time period for both the base and policy runs, while natural gas prices are specified only for the base cases, becoming a model output under very divergent drivers in each policy case. The second input category is initial

Box 2 continued

capital costs of major energy capital investments including electricity plant and transportation modes, both personal and freight. The third major input category is initial efficiencies of major energy capital in the electricity and transport sectors. Last, a range of additional model inputs has a much smaller impact on energy use and investment decisions. These include operation and maintenance (O&M) costs, energy infrastructure costs and efficiencies, and the distribution of plant lifetimes

Other key model inputs are driven by the model structure. For example, end-use efficiencies of the myriad equipment types in the industrial, commercial, and residential sectors are driven by the substitution elasticity between capital and energy. This determines what change in energy prices or equivalent change in investment hurdle rate is required to change energy use. These elasticities are highest in the commercial sector, followed by the industrial sector, with the residential sector having the lowest elasticity. This reflects the fact that the residential sector is least likely to respond to energy price changes, due to lack of information and available funds for efficiency investments among other reasons. A related and key model parameter is the investment hurdle rate (or discount rate). This varies between 12 percent and 25 percent according to the level of energy costs and the various programs designed to remove non-price barriers to investment. For more details on the model structure, see Appendix D and the references given there. Tables 4 through 9 include an illustrative set of key input assumptions used by the AMIGA model in this study. These include fuel prices as well as capital costs and efficiencies in the electricity and transportation sector.

emissions from their own operations. A comparison of studies based on a number of economic models[14] found that the quantity of domestic emissions reductions needed in the United States, the cost per ton of avoided emissions, and the overall impact of the emissions reduction program on the U.S. economy might be much less if international emissions trading, soil and plant carbon sequestration, and the opportunity to reduce other GHGs was available to U.S. companies. A study by Edmonds et al. (1999) found that to achieve the carbon reduction target of the Kyoto Protocol, allowing emissions trading among industrial countries could lower the level of carbon emissions reductions needed from the U.S. energy sector by 16 percent, while emissions trading with both industrial and developing countries could reduce the need for domestic energy sector reductions by 76 percent.[15]

Similarly, developing cost-effective carbon sequestration practices or utilizing available options for lowering emissions of non-CO_2 greenhouse gases (methane, nitrous oxide, and the industrial gases—HFCs, PFCs and SF_6) could also reduce the impact of a carbon reduction target on the U.S. energy sector. Recent analyses by Reilly and colleagues at MIT[16] suggests that mitigation of non-CO_2 gases could reduce the level of domestic carbon reductions required from the U.S. energy sector by 17 to 53 percent depending on the stringency and timing of the policy. Finally, the use of sequestration in soils and forestry can also contribute cost-effectively to national efforts to limit GHG emissions.[17]

Box 3

Components of the Climate Policy Modeled in these Scenarios

A portfolio of climate policies was imposed on the base case scenarios and simulated using the AMIGA model. The components of the policy overlay include a carbon emissions allowance cap-and-trade program for some sectors and a set of sector-specific equipment-efficiency credit trading programs. Other elements include R&D investments, targeted tax reforms, efficiency standards for residential, commercial, and industrial equipment, and some additional programs to reduce market imperfections.

The carbon emissions cap-and-trade program establishes a limit (or cap) on carbon emissions from utility electric generation and from large industrial sources. It distributes tradable allowances or permits to emit the designated amount of CO_2, and requires CO_2 emitters to surrender a quantity of allowances equal to their annual emissions. This program incorporates a flexible design similar to that of the U.S. EPA's sulfur dioxide (SO_2) allowance-trading program, with a fixed quantity of emission allowances distributed on an annual basis. The emission allowances can be traded across product lines and among manufacturers.

The price of carbon emission allowances affects energy prices throughout the economy. Thus, the allowance price affects the operations of and investments in both energy supply technologies and energy end-use systems. The allowance price for carbon emissions accelerates the adoption of energy efficiency-improving technologies in both the buildings and the industrial sectors. It also increases research and development (R&D) investments in new, low-emission, energy supply technologies. Energy supply technologies benefiting from these R&D investments include nuclear energy technologies, renewable energy technologies, distributed generation systems, hydrogen energy systems, and bio-fuels.

Other tradable emission credits introduced in this study are based on technology performance and carbon emission standards for manufactured products. Performance can be averaged between product lines and credits traded between manufacturers. This tradable credits program uses estimates of the average life and emissions of each manufacturer's products to translate over-compliance with a standard into a stream of vintaged emissions credits. Conversely, the program translates a failure to achieve the standard into an annualized deficit of credits that must be offset by credits purchased in the market. This is a "capped" tradable credits program, under which policy-makers set a cap on the total emissions associated with particular types of newly manufactured products. To sell products subject to the capped standard, manufacturers would have to obtain or surrender credits to ensure that they were in compliance at the end of each model year.

In the transportation sector, efficiency-trading programs for new equipment purchases are represented as the means for achieving sector-wide fuel economy targets. In effect, they allocate emissions credits on the basis of specified fuel efficiency targets for light-duty vehicles, heavy-duty vehicles, rail systems, and aircraft. These vehicle efficiency programs complement the carbon emission allowance cap-and-trade program, resulting in lower carbon allowance prices.

Investment in R&D significantly affects the rate of commercialization for efficiency-improving and emissions-reducing technologies in the policy overlay cases. The impact of these R&D expenditures is to lower the economic cost and improve the engineering performance of the targeted technologies. Varying amounts of public and private spending are devoted to R&D in each of the three policy overlay cases. Included among the technologies that receive targeted R&D support in the policy overlay cases are:

- Transportation-related equipment (e.g., hybrid gasoline-electric and diesel-electric vehicles, medium- and heavy-duty trucks, heavy rail systems, and aircraft);
- Moonshot program to promote the commercialization of fuel cells and hydrogen production, transmission, and distribution technology;
- Renewable energy technologies;
- IGCC technology; and
- Carbon capture and sequestration technology

In addition, targeted tax reforms are used in the policy overlay cases to accelerate the market penetration of key technologies. These include:

- Investment tax credits for highly efficient vehicles; and
- Tax credits for hydrogen production.

Efficiency standards for residential, commercial, and

Box 3 continued

industrial equipment help to raise the average efficiency of appliances, motors, lights, and other key energy-using devices. The model assumes that energy service companies are paid to reduce energy waste in these sectors.

Some additional programs to reduce market imperfections complement the programs described above. These "barrier-busting" programs are assumed to be necessary to achieve the cost trajectories for critical energy technologies that are incorporated in the policy overlay cases. They include:

- Information dissemination programs explaining the benefits of low-emission vehicles;
- Freight management programs to reduce idling by medium- and heavy-duty trucks;
- Improved fuel economy labels to inform the purchasers of new vehicles;
- Transportation management programs to reduce vehicle miles traveled in each vehicle class;
- Training programs for operating engineers in commercial buildings; and
- Programs to eliminate regulatory barriers to distributed generation, e.g., national interconnection standards and net metering.

Additional policies, not explicitly modeled in this study, could assist in overcoming remaining energy market imperfections. Overcoming these imperfections would increase economic efficiency in energy markets and further reduce carbon permit prices. Such policies include:

- Information and marketing programs for building owners and businesses;
- Energy-efficiency ratings for houses, appliances, and major energy consuming devices;
- Energy-efficiency mortgages to finance incremental investments in energy efficiency; and
- Cooperative industry programs including expanded programs of the type now known as EnergyStar and GasStar.

Table 4

Input Assumptions Concerning Global Oil Prices

All prices given in constant 2000 US$/barrel (bbl)

Year	Technology Triumphs		Awash in Oil and Gas		Turbulent World	
	Base	Policy	Base	Policy	Base	Policy
2000	$27.72	$27.72	$27.72	$27.72	$27.72	$27.72
2010	22.87	22.71	23.18	23.00	58.62	58.56
2020	22.46	21.37	23.52	21.40	46.60	45.90
2035	21.57	19.21	23.09	17.73	41.70	39.76

Table 5

Initial Input Assumptions Concerning **Natural Gas Prices** in the Base Cases*

All prices given in 2000 US$/mcf

Year	Technology Triumphs	Awash in Oil and Gas	Turbulent World
2000	$2.76	$2.76	$2.76
2010	2.64	2.68	4.04
2020	2.65	2.69	3.46
2035	4.04	4.18	4.58

* The AMIGA Model adjusts these parameters over the period of the policy overlay cases.

Table 6

Initial Input Assumptions* Concerning the **Costs and Efficiency of Electric Power Technologies****

Generating Technology	Capital cost ($/kWe)	Heat rate (BTU/kWh)	Efficiency (HHV)
Simple cycle gas turbine	$388	10,801	31.6%
Advanced gas turbine	438	10,212	33.4%
Natural gas combined cycle	590	7,110	48.0%
Advanced natural gas combined cycle	563	6,217	54.9%
Repower existing coal plant	1,250	10,188	33.5%
Advanced repowered coal plant	1,305	8,842	38.6%
IGCC	1,641	8,345	40.9%
Advanced IGCC	1,602	7,262	47.0%
Biomass gasification	1,714	9,534	35.8%
Advanced biomass gasification	1,714	8,910	38.3%
Wind electric	1,265	-	-
Geothermal	2,000	-	-
Advanced nuclear power plant †	2,645-2,835		
IGCC with carbon capture ‡	1,736		
Advanced IGCC with C capture ‡	1,667		

Notes:

* The Pew Center and Argonne National Laboratory provided data presented in this table. Values reflect a range of findings in recent published literature.

** These initial values are adjusted over time by the model as it plays out each scenario; adjustments vary by scenario. The model projects future technology costs and efficiencies in the period 2010 to 2035 as a function of the level of research investment made during each base case scenario or policy overlay case in each candidate technology.

† Advanced nuclear power plants are assumed to cost $2,645 per kWe in *Technology Triumphs* and $2,835 in both *Turbulent World* and *Awash in Oil and Gas*. Other analysts foresee lower capital costs for advanced nuclear plants.

‡ The estimated cost range for carbon capture and sequestration is $45 to $300 per ton of carbon with median estimates $120 per ton of carbon captured in *Technology Triumphs*, $160 per ton in *Turbulent World*, and $200 per ton in *Awash in Oil and Gas*.

Table 7

Input Assumptions Concerning **On-Road Fuel-Economy** (MPG gasoline equivalent) for Medium Sized Cars

	2000	2010		2020		2035	
Technology Triumphs		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	21.99	31.57	31.57	31.73	31.73	31.73	31.73
Dedicated CNG Vehicle	-	31.57	31.57	31.73	31.73	31.73	31.73
Advanced Diesel & other adv ICEs	-	44.1	44.1	44.26	44.26	44.26	44.26
Hybrid Electric Vehicle	-	46.94	46.94	55.40	55.40	61.21	61.21
FCV with on-board reformer	-	-	-	-	-	61.87	65.72
Hydrogen FCV	-	-	-	-	76.27	91.33	91.33

	2000	2010		2020		2035	
Awash in Oil and Gas		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	21.99	24.31	25.52	24.43	31.73	24.43	31.73
Dedicated CNG Vehicle	-	24.31	25.52	24.43	31.73	24.43	31.73
Advanced Diesel & other adv ICEs	-	-	-	34.08	44.26	34.08	44.26
Hybrid Electric Vehicle	-	-	-	39.26	50.99	47.13	61.21
FCV with on-board reformer	-	-	-	44.86	58.26	50.6	65.72
Hydrogen FCV	-	-	-	-	-	63.12	81.97

	2000	2010		2020		2035	
Turbulent World		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	21.99	31.57	31.57	31.73	31.73	31.73	31.73
Dedicated CNG Vehicle	-	31.57	31.57	31.73	31.73	31.73	31.73
Advanced Diesel & other adv ICEs	-	44.10	44.10	44.26	44.26	44.26	44.26
Hybrid Electric Vehicle	-	46.94	46.94	55.40	55.40	61.21	61.21
FCV with on-board reformer	-	-	-	61.87	61.87	65.72	65.72
Hydrogen FCV	-	-	-	-	76.27	91.33	91.33

Notes: Data on assumed fuel economy by drive train type are illustrative and derived from estimates prepared by US Department of Energy and Argonne National Laboratory.
FCV means Fuel Cell Vechicle.

Table 8

New Vehicle Purchase Price Assumptions (2000$) for Medium Sized Cars (Full-cost price before imposition of a permit charge or credit)

	2000	2010		2020		2035	
Technology Triumphs		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	$24,383	$26,286	$26,286	$26,977	$26,977	$26,977	$26,977
Dedicated CNG Vehicle	-	27,401	27,401	28,092	28,092	28,092	28,092
Advanced Diesel & Other Advanced ICEs	-	27,677	27,677	28,368	28,368	28,368	28,368
Hybrid Electric Vehicle	-	31,899	31,899	29,797	29,797	28,343	28,343
FCV with on-board reformer	-	-	-	36,854	36,854	32,549	32,549
Hydrogen FCV	-	-	-	-	33,907	31,112	31,112

	2000	2010		2020		2035	
Awash in Oil and Gas		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	$24,383	$25,761	$25,848	$26,438	$26,977	$26,438	$26,977
Dedicated CNG Vehicle	-	26,853	26,944	27,530	28,092	27,530	28,092
Advanced Diesel & Other Advanced ICEs	-	-	-	28,803	29,391	28,803	29,391
Hybrid Electric Vehicle	-	-	-	32,370	33,031	29,781	30,389
FCV with on-board reformer	-	-	-	38,271	39,052	33,903	34,595
Hydrogen FCV	-	-	-	-	-	34,110	34,807

	2000	2010		2020		2035	
Turbulent World		**Base**	**Policy**	**Base**	**Policy**	**Base**	**Policy**
Conventional Vehicle	$24,383	$26,286	$26,286	$26,977	$26,977	$26,977	$26,977
Dedicated CNG Vehicle	-	27,401	27,401	28,092	28,092	28,092	28,092
Advanced Diesel & Other Advanced ICEs	-	28,700	28,700	29,391	29,391	29,391	29,391
Hybrid Electric Vehicle	-	33,945	33,945	31,842	31,842	30,389	30,389
FCV with on-board reformer	-	-	-	38,900	38,900	34,595	34,595
Hydrogen FCV	-	-	-	-	35,953	33,157	33,157

Table 9

Amortized Cost of Efficiency Improvements (in 2000$/MBtu Saved)

	Awash in Oil and Gas	Technology Triumphs	Turbulent World
Electricity Improvements			
Residential	$15.48	$15.47	$16.26
Commercial	15.17	15.53	16.07
Industrial	12.13	12.31	13.16
Natural Gas Improvements			
Residential	$4.86	$4.78	$5.51
Commercial	3.21	3.22	3.71
Industrial	6.18	5.97	6.76

Notes: These are the assumptions for average cost of energy saved (2000$/MBtu) evaluated at a 13 percent real return on capital invested. They are used to calculate the cost of energy efficient investments induced by the policy overlay in each scenario in 2035. The values are based on elasticities of substitution between energy use and specific energy-using capital. The assumed elasticities by sector are residential, 0.55; commercial, 0.75; and industrial, 0.65.

C. Implementing the Policy Overlay Changes the Future

Each of the base case scenarios reflects a unique pattern of external events, public policies, technological choices, energy supply and demand, prices, consumption, and investment. For example, in *Awash in Oil and Gas,* low oil and gas prices and abundant fuel supplies stimulate a pattern of energy consumption that produces high levels of carbon emissions. Another effect of low oil and gas prices is to discourage investment in energy efficiency-improving measures and carbon reducing technologies. This reduced rate of public and private investment leads to slower rates of technological advance and smaller cost reductions for the technologies that would be critically needed under a tight constraint on energy-related carbon emissions. Thus in the policy overlay case associated with *Awash in Oil and Gas,* the cost to the economy of meeting the hypothetical carbon constraint analyzed here is substantially higher (and the policies necessarily much more stringent) than is the case in either *Technology Triumphs* or *Turbulent World.*

Exploration of the policy overlays for the three scenarios suggests that it might be possible to meet future requirements for carbon emissions reductions, no matter what direction the future takes. However, in *Technology Triumphs,* early and consistent investment in clean and efficient energy technologies contributes to strong economic growth and leaves the United States better positioned to reduce GHG emissions in the future.

The *Awash in Oil and Gas* base case is a world where there are very few worries about energy in the United States. Imposing the climate policy overlay on this base case scenario introduces significant tensions throughout U.S. society in the first half of *Awash in Oil and Gas with Policy.* Whereas low oil and gas prices tended to drive up oil and gas demand in the base case, the carbon emissions constraint in the policy overlay case tends to drive down this demand. Although federal programs provide information to consumers and investors in a broad array of forms, helping them to understand the climatic consequences of their energy use, low prices continue to send a conflicting signal. Consumers read ENERGY STAR labels on new appliances; industrial managers participate in seminars on new and cost-effective energy management measures; and drivers receive information on how to avoid congested roads. Still, old habits hang on. Compliance with energy performance standards for new equipment is good, but the tendency to disregard energy costs leads to increased driving and minimal attention to the behavioral aspects of energy conservation.

In *Awash in Oil and Gas with Policy,* the strong lure of cheap fuels and the tight carbon constraint cause both the public and private sectors to invest heavily in new carbon capture and sequestration technologies. These efforts prove successful and begin to ease some of the tensions in the latter half of *Awash in Oil and Gas with Policy.* In *Awash in Oil and Gas with Policy,* the trend toward increasing use of natural gas in the electricity sector (already visible in the base case) is amplified, accelerated, and becomes coupled with carbon capture and sequestration. As carbon capture and sequestration technology becomes commercially successful, the U.S. domestic resource of inexpensive and readily accessible underground cavities begins to fill up. This necessitates the development of deeper, higher cost resources (including some brine-filled reserviors that lack complete stratigraphic traps or seals).

Also in the latter half of *Awash in Oil and Gas with Policy,* concerns about air pollution (which were by themselves insufficient to drive much change in transportation technology) combine with the effects of the carbon emissions constraint and lead to increased investment in improved transportation technology. The combined effect of the shift to more efficient and lower-emission vehicles reduces CO_2 emissions from the transportation sector by 55 percent in *Awash in Oil and Gas with Policy* compared to the base case scenario.

The carbon emissions constraint in *Technology Triumphs with Policy* reinforces the four principal driving forces in the base case scenario, further accelerating the commercialization of key technologies. In particular, the carbon constraint provides an added impetus to lower the barriers to commercialization for DG, renewable energy, and energy efficiency technologies. This constraint also has a transforming effect on the U.S. transportation sector. From the individual automobile, to heavy trucks, buses, and jet airplanes, new technologies and new management practices dramatically improve the efficiency with which transportation services are delivered to end-users. In this policy overlay case, climate policy is relatively uncontroversial because of the plethora of available technological "solutions" that are convenient, reliable, and cost-effective. In *Technology Triumphs with Policy,* the United States becomes a formidable international competitor in the development of the next generation of energy supply and end-use technologies. The United States becomes a significant exporter of DG, renewable energy, and energy efficiency technologies, as well as of advanced vehicles.

In the electricity sector of *Technology Triumphs with Policy,* new energy efficiency-improving technologies slow the rate of growth in energy demand, without damaging the general economy. As DG and renewable energy technologies mature, they capture increasing shares of the electricity market, abetted by state and federal policies to promote their use.

In the transportation sector, hybrid gasoline-electric and diesel-electric vehicles and advanced internal combustion engines (ICEs) achieve early and rapid penetration in *Technology Triumphs with Policy.* As the light-duty vehicle market evolves in *Technology Triumphs with Policy,* carbon emissions from the U.S. transportation sector decline by 44 percent, compared to the *Technology Triumphs* base case scenario.

In *Turbulent World with Policy,* U.S. policy-makers focus on a combination of energy security and climate change concerns. The imposition of a carbon emissions constraint leads to a significant reduction of oil demand and a consequent reduction in CO_2 emissions. Due to the high costs and uncertain availability of oil products in *Turbulent World,* the introduction of vehicle efficiency standards and traffic management systems are both popular and cost-effective in *Turbulent World with Policy.* In this policy overlay case, advanced vehicles sweep the market for new light-duty vehicles. The successful federal "moonshot" program rapidly accelerates the development of fuel cells and hydrogen. In the transportation sector, the deployment of fuel cell vehicles allows the United States to substitute hydrogen derived from coal for imported oil. This lowers the risks to energy security associated with oil import dependence and reduces emissions of CO_2, as well as a variety of air pollutants, including NO_x, volatile organic compounds, and particulates. With the introduction of advanced vehicles, by 2035, carbon emissions from the transportation sector are 40 percent lower in the policy overlay case than in the base case scenario.

In the electric sector of *Turbulent World with Policy,* new emphasis on issues of facility security combines with the carbon emissions constraint to encourage the widespread use of DG. An expanded "moonshot" program becomes the lynchpin of U.S. energy policy, radically transforming the electricity sector as well as the transportation sector. Due to the expanded "moonshot" program, fuel cells using hydrogen derived from coal play an increasingly important role in electricity generation in this policy overlay case. In addition, the "moonshot" program in *Turbulent World with Policy* leads to the commercialization of IGCC power plants that are coupled with technologies for hydrogen production and CO_2 sequestration. By 2035, central-station CO_2 emissions fall by 40 percent in *Turbulent World with Policy,* compared to the base case scenario.

D. Observations and Results

The quantitative results described in this section are based on model simulations of the Pew Center scenarios with and without the hypothetical policy overlay. They are dependent upon the assumptions made and the model used in this project. Like the scenarios themselves, the quantitative results are not meant to be predictive, but rather to compare and contrast these alternative futures.

Typically, climate policy analyses create one base case forecast, analyze various policy options, and draw conclusions as to the relative merits of these various policies. This scenario planning exercise takes a very different approach: it takes three different base case scenarios (not forecasts), analyzes the effect of the same portfolio of policies on each of them, and draws conclusions as to the relative difficulty of implementing the policy overlay under the different scenarios. Since only one policy overlay was analyzed, one cannot draw conclusions about its merits relative to other polices.

Population growth is a key factor affecting energy use. U.S. population growth was treated as exogenous to this exercise and was assumed to be the same in all three base case scenarios and their policy overlay cases. The U.S. population was assumed to grow by one-third, from about 280 million people in 2000 to approximately 370 million people in 2035. The increasing size of the U.S. population and the increased level of aggregate energy use in the U.S. economy explain part of the increase in carbon emissions that occurs in the absence of a climate change policy in all three Pew Center base case scenarios.

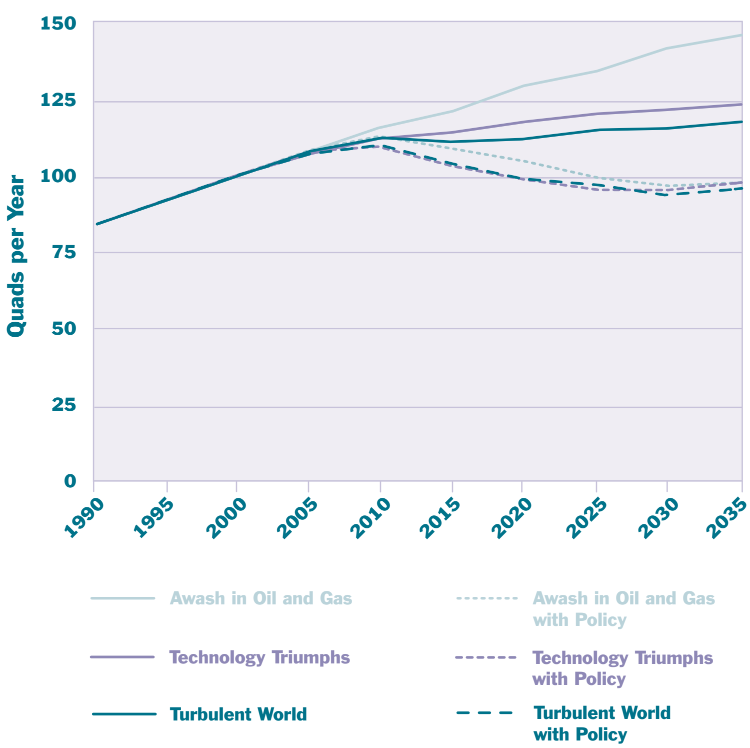
Energy, Economics, and Carbon Emissions

Primary Energy Use

Growth in total primary energy ranges from 20 percent to 50 percent in the three base case scenarios. Figure 1 illustrates the large differential in total primary energy use from 2000 to 2035 among the Pew Center scenarios and their associated policy overlay cases. In 2035, total primary energy demand is approximately 120 Quads in *Turbulent World* base case, approximately 125 Quads in *Technology Triumphs* base case, and 150 Quads in *Awash in Oil and Gas* base case. This compares to the historical level of 100 Quads in 2000. In the three policy overlay cases, total primary energy use in 2035 is significantly lower than in the base cases, and is slightly lower than year 2000 levels. The variation in energy use among the three policy overlay cases is less than two quads in 2035.

Figure 1

Primary Energy



Expenditures on Fuels and Electricity

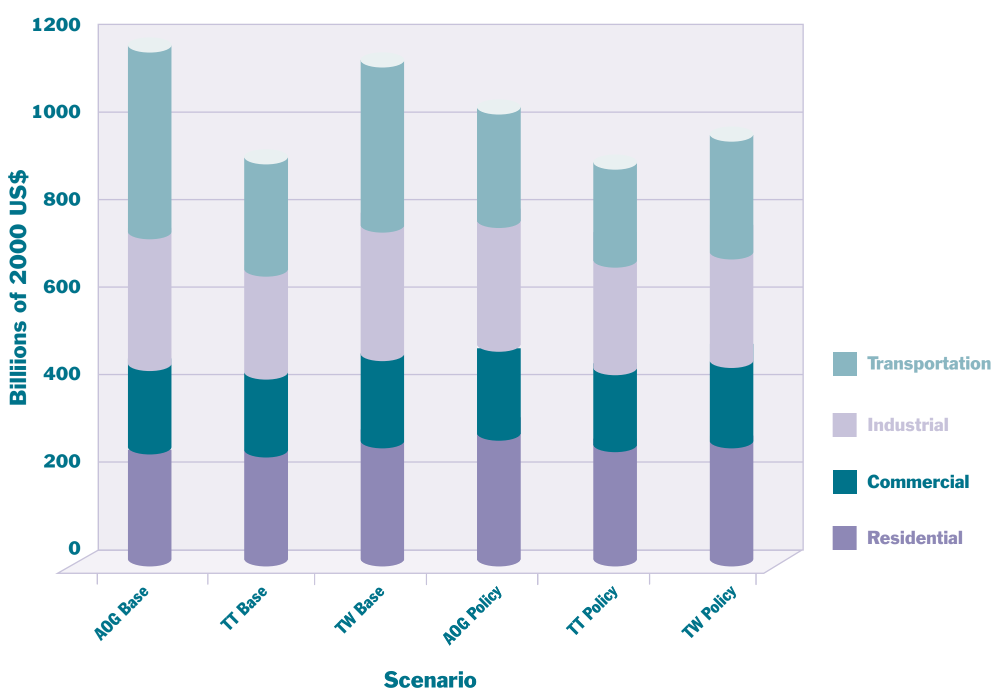
Energy expenditures represent the amount spent on purchasing fuels or electricity. The magnitude of these expenditures is the product of the quantity of energy multiplied by the price of fuels and electricity, respectively. Figure 2 below illustrates the aggregate level of energy expenditures and their sectoral breakdown (in billions of constant dollars) for 2035 in the three base case scenarios and their respective policy overlay cases.

The sectoral pattern of energy expenditures varies considerably, by up to 60 percent among the three base case scenarios, and by up to 20 percent among the policy overlay cases. Two of the three base case scenarios, *Awash in Oil and Gas* and *Turbulent World,* have significantly higher energy expenditures than the *Technology Triumphs* base case. The differences between these base cases are largely driven by differences in energy prices among the scenarios and by variation in the level of energy demand for the transportation sector. In *Awash in Oil and Gas,* for example, high oil demand leads to high levels of expenditures; in *Turbulent World,* high oil prices are the principal driver. *In Technology Triumphs,* improved efficiency lowers oil demand for transportation and leads to lower overall energy expenditures.

For the three policy overlay cases, the imposition of a carbon constraint lowers demand for fuels in the transportation sector. As a result, in *Awash in Oil and Gas with Policy,* energy expenditures for transportation decline by 36 percent relative to the *Awash in Oil and Gas* base case. In *Turbulent World with Policy,* the carbon constraint leads to higher transportation efficiency and 30 percent lower

Figure 2

Energy Expenditure by Sector in 2035



expenditures on transportation fuels. By contrast, the change in expenditures for fuels in *Technology Triumphs with Policy* is relatively small compared to its base case, because the base case scenario is already very efficient. In *Technology Triumphs with Policy,* additional improvements in transportation efficiency are offset by the increases in fuel costs induced by the carbon constraint.

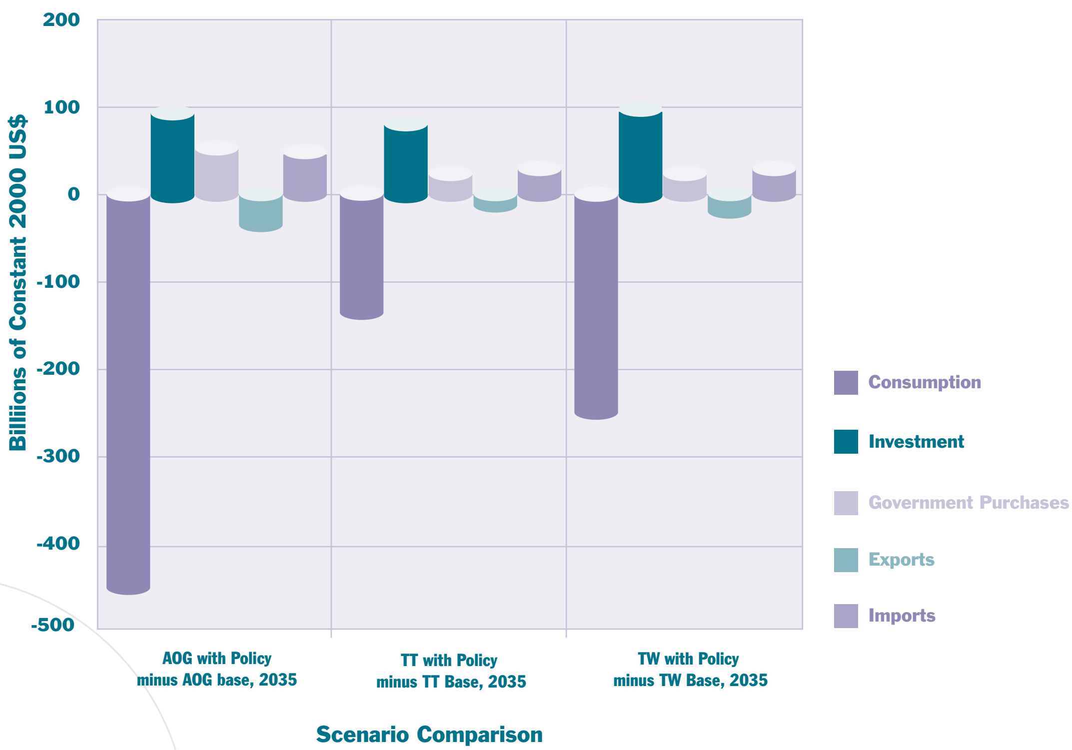
Economic Activity in the Pew Center Scenarios

This scenario planning exercise was not designed to forecast the impacts of climate change policies on the U.S. economy. However, in broad terms, this analysis is consistent with the literature on these economic impacts. The quantitative results of this study are presented below primarily to facilitate comparisons among the scenarios, and also to increase the reader's understanding of the scenario dynamics.

The key economic insights gleaned from this modeling exercise are relative. First, the difficulty of reaching a particular CO_2 emissions target in a given future year depends on the pattern of energy supply and use in a given scenario. For example, the projected impact on GDP in 2035 of overlaying the portfolio of carbon emissions reduction policies in *Awash in Oil and Gas* is more than five times as large as when the same portfolio of policies is implemented in the *Technology Triumphs* scenario. Similarly, the impact of the policy overlay when imposed on the *Turbulent World* scenario is more than twice as large as when this policy overlay is imposed in *Technology Triumphs.*

Figure 3

Differences between major **Components of GDP in 2035** in each policy scenario compared to its associated base case



This result occurs because the economy in *Awash in Oil and Gas* is on a trajectory of high consumption and high levels of fossil fuel use, and reducing emissions from this trajectory leads to a more difficult (and more costly) transition. By contrast, to a great extent in *Technology Triumphs* and to some extent in *Turbulent World*, base case investment in new technology both bolsters key sectors of the economy and also reduces the cost of achieving the carbon constraint in the policy overlay cases.

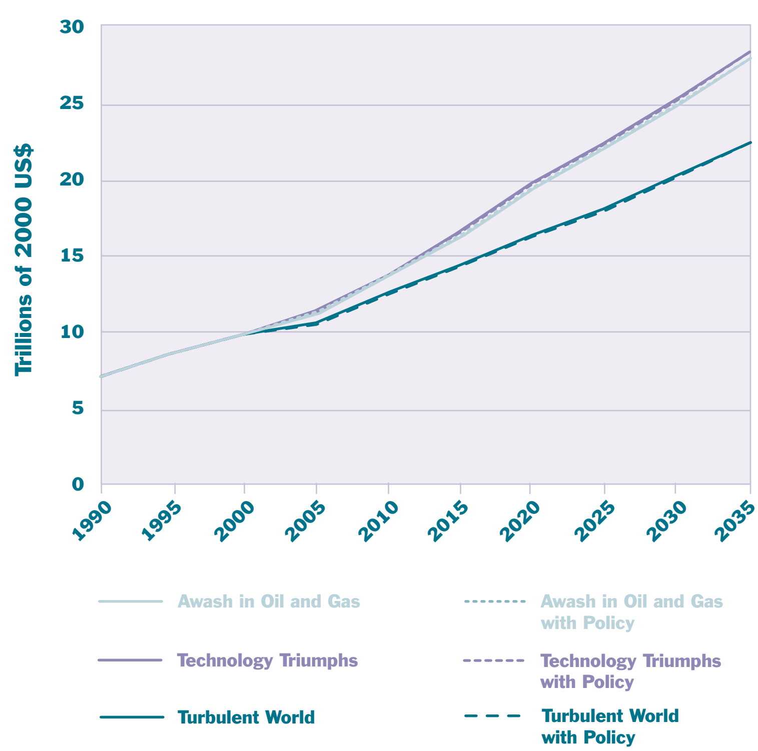
Second, this analysis finds that the economic impact of implementing the policy overlay is small as a percentage of GDP, but there are significant costs, especially for the energy and energy-intensive sectors. However, the hypothetical policy overlay explored in this study did not take into account the various flexibility mechanisms that the literature indicates could substantially lower future costs of carbon emissions reductions.[19]

Third, implementing climate policies affects the balance among major macroeconomic components of GDP (i.e., personal consumption, real investment, government spending, imports, and exports). Figure 3 illustrates these effects on the composition of GDP, showing the difference between the estimated values of each macroeconomic component for 2035 in the base case scenarios and their respective policy overlay cases. In each policy overlay case, increased public and private investment as well as reduced fossil fuel imports partially offset the decline in consumption.

Fourth, Figure 4 illustrates the AMIGA model estimates of GDP from 2000 to 2035 in the three base case scenarios and their respective policy overlay cases. Across the scenarios, projected GDP in 2035 is in the range of $22 to $28 trillion (in constant dollars), compared to approximately $10 trillion in 2000. In economies that have more than doubled by 2035, aggregate GDP is 0.2 percent smaller in *Technology Triumphs with Policy* than in its base case, 0.8 percent smaller in *Turbulent World with Policy*

Figure 4

Gross Domestic Product



compared to its base case, and 1.4 percent smaller in *Awash in Oil and Gas with Policy,* compared to its base case scenario.

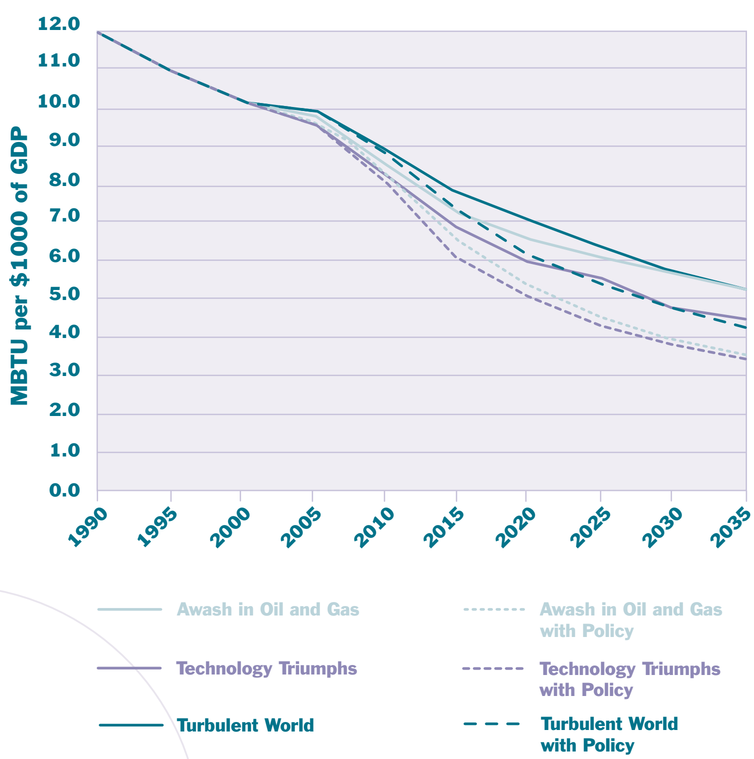
GDP growth rates for the base case scenarios were inputs to the modeling analysis and were chosen to be consistent with the narratives. In contrast, GDP growth rates in the policy overlay cases were model outputs. The annual GDP growth rate assumptions for the base case scenarios were 3 percent for *Technology Triumphs*, 2.4 percent for *Turbulent World*, and 3 percent for *Awash in Oil and Gas*.

Energy Intensity of the U.S. Economy

The energy intensity of the U.S. economy declined from the late 1970s to 2000, and continues to decline in all three scenarios, albeit at somewhat different rates. Figure 5 illustrates the declining level of energy intensity (measured in millions of Btu per $1000 of GDP) in the base case scenarios and their respective policy overlay cases. In each policy overlay case, introduction of climate policies accelerates the shift away from energy-intensive manufacturing and toward less energy-intensive service sectors of the economy. In the base case scenarios, the energy intensity of the U.S. economy declines by about half during 2000 to 2035. In the policy overlay cases, energy intensity declines by about two-thirds, from 10 million Btu (MBtu) per $1000 of GDP in 2000 to 3.4 to 4.3 MBtu per $1000 of GDP in 2035.

Figure 5

Energy Intensity of the U.S. Economy



U.S. Carbon Emissions from Fossil Fuel Combustion

As shown in Figure 6, in the absence of policy designed to reduce carbon emissions, future U.S. carbon emissions remain well above their year-2000 level in all three base case scenarios. Emissions in 2035 vary significantly among the base scenarios, from 15 to 20 percent higher than their year-2000 level in *Technology Triumphs* and *Turbulent World* base case scenarios, to 50 percent higher in the *Awash in Oil and Gas* base case. Because of the shared constraint on carbon emissions in the policy overlay cases, carbon emissions in all three of these policy overlay cases decline to about 970 MMTC, or 38 percent below the year-2000 level in 2035.

Figure 6

U.S. Carbon Emissions from Fossil Fuel Combustion

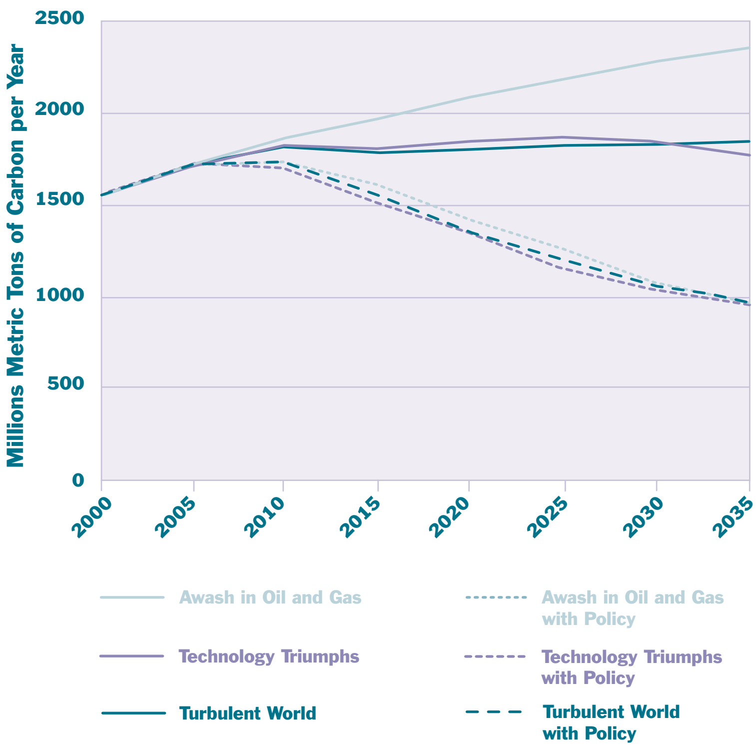


Figure 7

Carbon Intensity of the U.S. Economy

Carbon Intensity of the U.S. Economy

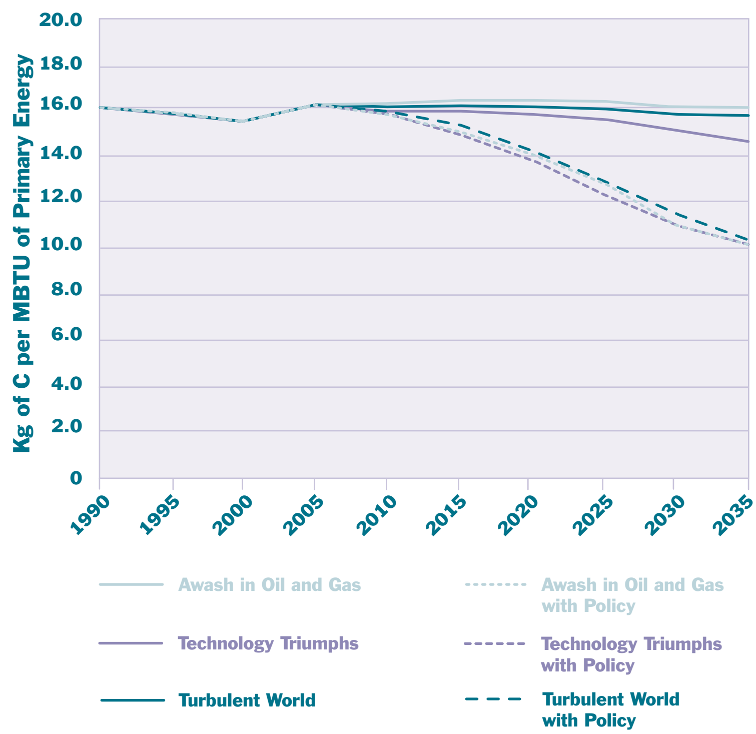
The variation in future carbon emissions among the scenarios is a consequence of several factors. Carbon intensity in the U.S. economy declined by 17 percent from 1990 to 2000, and the decline continues in all three scenarios and their respective policy overlay cases, although at different rates. Figure 7 illustrates the historical trend and the continuing decline in carbon intensity of the U.S. economy in each base case scenario and its associated policy overlay case. In the three base case scenarios, the carbon intensity of the economy (measured in kilograms of carbon per $1000 of GDP) declines to less than half the 1990 level by 2035. Introduction of climate policies accelerates the historic shift away from energy-intensive manufacturing and toward less energy-intensive service sectors of the economy, which reduces carbon intensity in the U.S. economy from 160 kg of carbon per $1000 of GDP in 2000 to approximately 40 kg of carbon per $1000 in 2035.

Carbon Emissions per Unit of Primary Energy Consumed

The carbon intensity of energy use also declines significantly during this period, reflecting not only increasing investment in energy efficiency technologies but also a shifting fuel mix. The balance between factors contributing to the declining carbon intensity of the energy sector varies among the base case scenarios and their respective policy overlays. But one factor remains a constant: the carbon intensity of the economy declines as the market share of natural gas expands in all scenarios, both in the electricity sector and in other parts of the economy. For the base case scenarios, the carbon intensity of U.S. energy use declines from about 16 kg of carbon per MBtu of energy in 2000 to approximately 15 kg of carbon per MBtu in 2035. In the policy overlay cases, carbon intensity of energy use declines much more rapidly, falling to approximately 10 kg of carbon per MBtu of energy in 2035. Figure 8 illustrates the trajectory of carbon intensity per unit of energy in the three base case scenarios and their policy overlay cases. In all

Figure 8

Carbon **Emissions per Unit of Primary Energy**



cases, the fuel mix that contributes to U.S. primary energy supply becomes less carbon-intensive during the period from 2000 to 2035.

Figure 9 illustrates that the dynamics of the base case scenarios and the policy overlay cases significantly affect the U.S. fuel mix between 2000 and 2035. For example, petroleum's share of the U.S. fuel mix was approximately 38 percent in 2000. By 2035, its share of primary energy increases to 41 percent in the *Awash in Oil and Gas* base case, but declines in the two remaining base case scenarios and the three policy overlay cases to 23 to 30 percent of primary energy supply.

The market share of natural gas, which represented 23 percent of U.S. primary energy supply in 2000, increases in each base case scenario and in all policy overlay cases. In the base case scenarios, its share increases to 29 to 38 percent by 2035. The shift to natural gas becomes even more dramatic in the three policy overlay cases as the U.S. moves to a less carbon-intensive energy economy. Natural gas contributes 33 percent of primary energy in *Turbulent World with Policy* in 2035, 38 percent in *Technology Triumphs with Policy,* and 42 percent in *Awash in Oil and Gas with Policy.*

The contribution of coal to U.S. primary energy supply varies even more widely across the scenarios and their policy overlay cases. The market share for coal, which contributed 23 percent of U.S. primary energy in 2000, increases to 28 percent in *Turbulent World* base case by 2035 but falls in the other two base case scenarios to 13 percent in *Awash in Oil and Gas* base case and to 17 percent in *Technology Triumphs* base case. Under the carbon constraint imposed in the three policy overlay cases, the market share of coal in U.S. primary energy supply falls to 3 percent in *Awash in Oil and Gas with Policy,* to 12 percent in *Technology Triumphs with Policy,* and to 20 percent in *Turbulent World with Policy.*

Figure 9

Fuel Mix in U.S. Primary Energy Supply in 2035

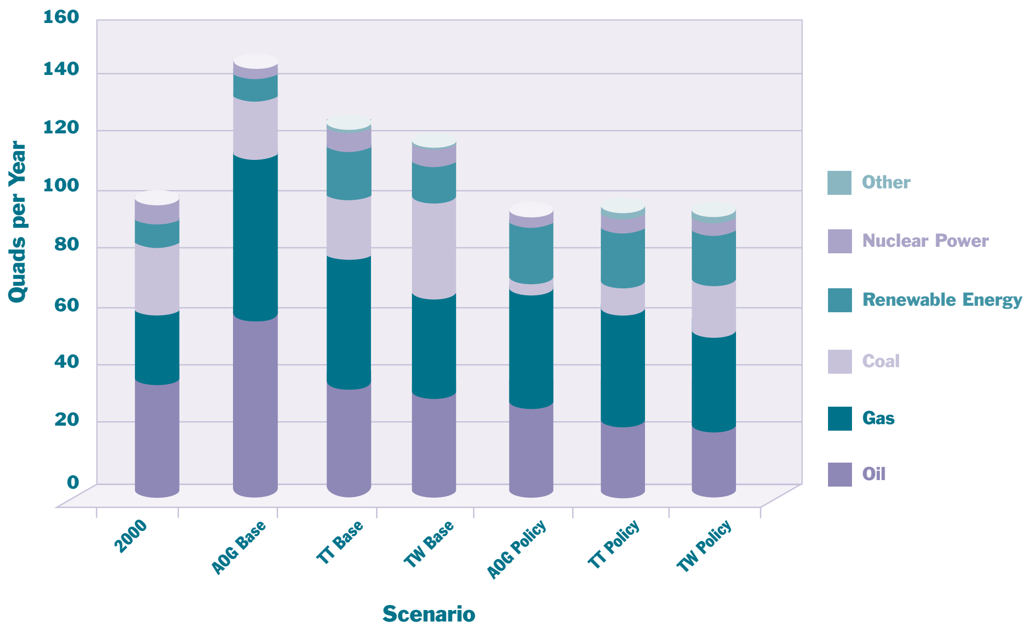
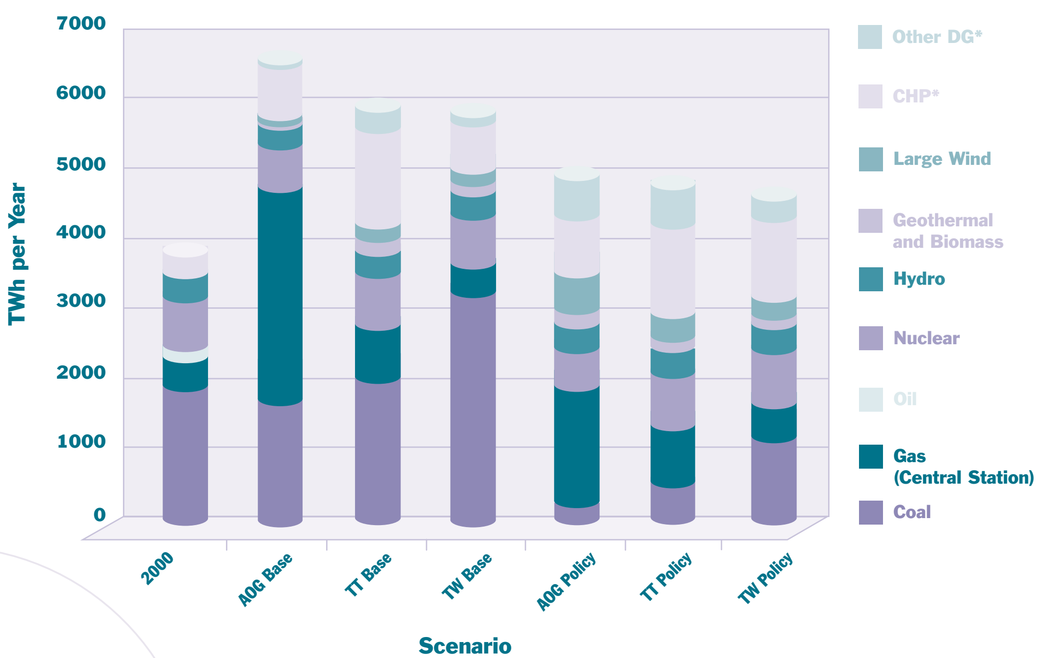


Figure 10

Contributions to **Electricity Supply** by Technology in 2000 and in 2035



*Note: most CHP and DG are natural-gas fired.

Electricity Generation

Electricity generation produced about one-third of U.S. CO_2 emissions in 2000. Figure 10 illustrates the change in the fuel mix of electric generation in 2035 compared to 2000 for the three base case scenarios and their policy overlay cases. In parallel to the situation for economy-wide primary energy (see Figure 9), the carbon intensity of electricity production decreases in both the base case and the policy overlay scenarios. This decline results from a combination of switching to less carbon-intensive fuels and the introduction of lower-emitting power production technologies.

In the base case scenarios, natural-gas fired electricity generation sees considerable growth in *Technology Triumphs,* mainly due to technological innovation and rising consumer demand for electricity. Growth in the share of electricity produced with natural gas is even more rapid in *Awash in Oil and Gas,* due to strong economic growth combined with low price and broad availability of this fuel. Growth in gas use for electricity is more modest in the *Turbulent World* base case, restrained in part by concerns over gas supply and site security issues. Use of natural gas captures a significantly larger market share in *Technology Triumphs with Policy* and in *Turbulent World with Policy*. Although total electricity demand is much lower in *Awash in Oil and Gas with Policy,* the market share for natural gas in electricity production from central station plants grows to over 40 percent of electricity supply in 2035, compared to approximately 15 percent in 2000.

In each of the three policy overlay cases, a growing use of high-efficiency CHP technology is responsible for a significant fraction of the growth in natural gas demand in the U.S. power sector. Gas-fired CHP also figures prominently in the *Technology Triumphs* base case because it fits well with that scenario's emphasis on improved efficiency. Similarly, in the *Awash in Oil and Gas* base case, gas is so cheap that industrial users are more likely to generate their own electricity from on-site facilities.

In absolute terms, coal nearly maintains or increases its contribution to electricity supply in all of the base case scenarios. The *Turbulent World* base case shows a surge in coal use associated with greater reliance on domestic resources. By contrast, coal use declines by varying degrees in all the policy scenarios. The decline is smallest in *Turbulent World with Policy,* where there is successful development of IGCC technology, combined with carbon capture and geological sequestration. In addition, the direct use of coal to produce hydrogen also boosts total coal demand in *Turbulent World with Policy.*

In both *Technology Triumphs with Policy* and *Awash in Oil and Gas with Policy,* coal's electricity market share drops considerably. This may reflect the potential significance of carbon capture and geological sequestration technology and coal-based hydrogen production to coal's future in a carbon constrained world.

In all the policy cases by 2035, renewable energy (including wind, solar, geothermal, biomass, and waste) and DG (including fuel cells and building-integrated photovoltaic power systems) technologies, see strong growth from their limited base of installed capacity in 2000. The base cases are more divergent, with *Awash in Oil and Gas* showing the smallest market penetration for these technologies. *Technology Triumphs* base case, however, illustrates considerable growth in renewable energy technologies and distributed generation, largely because these technologies meet the demand in this scenario for cleaner and smaller power generation units.

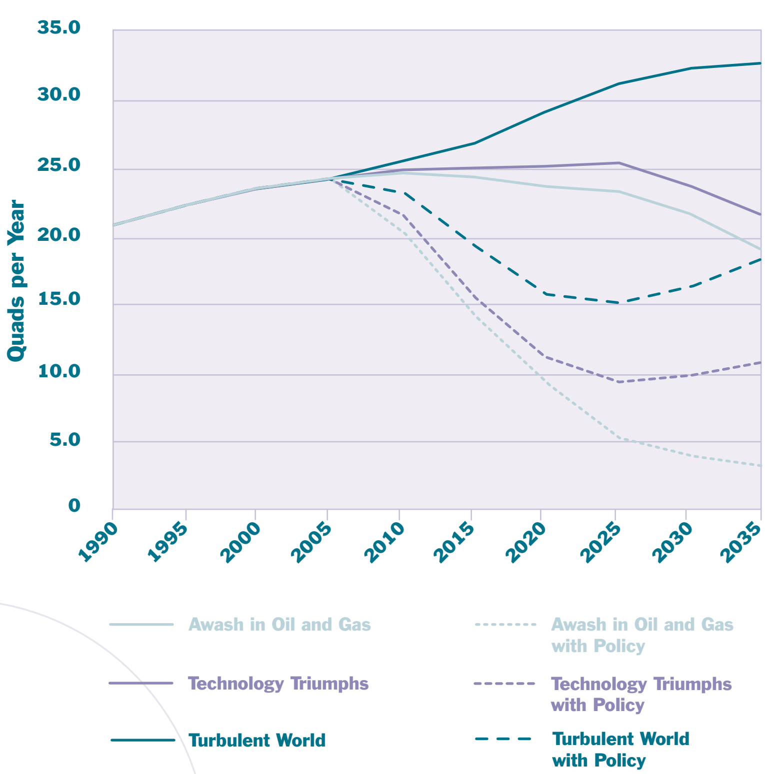
Finally, nuclear and hydroelectric power show the least change from historical production levels in the Pew Center base cases and the associated policy overlay scenarios. Nonetheless, both technologies retain significant market share. Very few hydroelectric plants are built or retired in these scenarios. The nuclear industry builds a few next-generation reactors in *Turbulent World,* until security fears inhibit further construction. In *Awash in Oil and Gas,* the gradual retirement of nuclear plants is hastened by the availability of cheap alternative fuel sources, and nuclear generation remains constant in *Technology Triumphs* as new advanced reactors and upgrades at existing facilities just offset nuclear plant retirements.

Coal

Historically, coal-fired power plants have been the largest single source of electricity (and of carbon emissions from the electricity sector) in the United States. In the absence of carbon sequestration, the use of coal-fired electric generation significantly affects the carbon intensity of the U.S. electricity sector, as well as the level of carbon emissions from the U.S. economy as a whole. Figure 11 shows coal consumption throughout the economy, including coal used both to generate electricity and to produce hydrogen.

Figure 11

Coal Consumption for Electricity Generation and Hydrogen Production



In the absence of a climate policy, nearly all coal use is for electricity production. The amount of coal consumed in 2035 varies by about 70 percent across the base case scenarios, from 19 Quads per year in *Awash in Oil and Gas* to 33 Quads per year in *Turbulent World.* Early in *Awash in Oil and Gas,* coal competes successfully with other fossil fuels, but later in this scenario the advance of high-efficiency natural gas combined cycle power plants, coupled with the expected retirement of a number of older coal fired power plants, causes coal to lose market share. *In Technology Triumphs,* much of the demand for new generation capacity is met by renewable and distributed generation, encouraged by the convergence of state-level policies, private investment, consumer demand, and technological success. By contrast, coal continues its dominant role in the electricity sector in *Turbulent World,* reflecting this scenario's policy orientation toward increasing reliance on domestic resources, especially the "moonshot" to produce fuel cells that burn hydrogen from coal.

In *Turbulent World with Policy,* coal first declines as old plants retire, but then comes back as IGCC technology captures significant market share by 2020, enabling the development of cost-effective technologies for co-production of hydrogen and for CO_2 capture and sequestration. In *Turbulent World with Policy,* coal consumption in 2035 is approximately 20 percent less than occurred in 2000. However, in both *Awash in Oil and Gas with Policy* and in *Technology Triumphs with Policy,* the implementation of a downstream cap-and-trade system has a major downward impact on coal consumption. In *Technology Triumphs with Policy,* coal consumption for electricity and hydrogen production declines to about half of its year 2000 level by 2025, but then begins to increase again because of the success of advanced coal technology. In *Awash in Oil and Gas with Policy,* coal use for electricity and hydrogen production declines steadily, falling by 2035 to 13 percent of the overall level of coal use in 2000.

This suggests that the coal industry's future in the U.S. under the carbon policy overlays examined here is heavily dependent on the development of cost-effective IGCC technology with hydrogen co-production. However, this analysis was limited to U.S. energy supply and use. It did not take into account opportunities to offset CO_2 emissions through carbon sequestration in soils and vegetation, international emissions trading, or reductions in non-CO_2 gases. Under a carbon constraint, any negative impact on coal consumption in the United States might be limited by allowing coal-fired plants the flexibility to ffset their emissions. Also, a more gradual carbon reduction than that hypothesized in this exercise might avoid the situation in which coal use first declines and then revives as advanced coal technology becomes cost-effective.

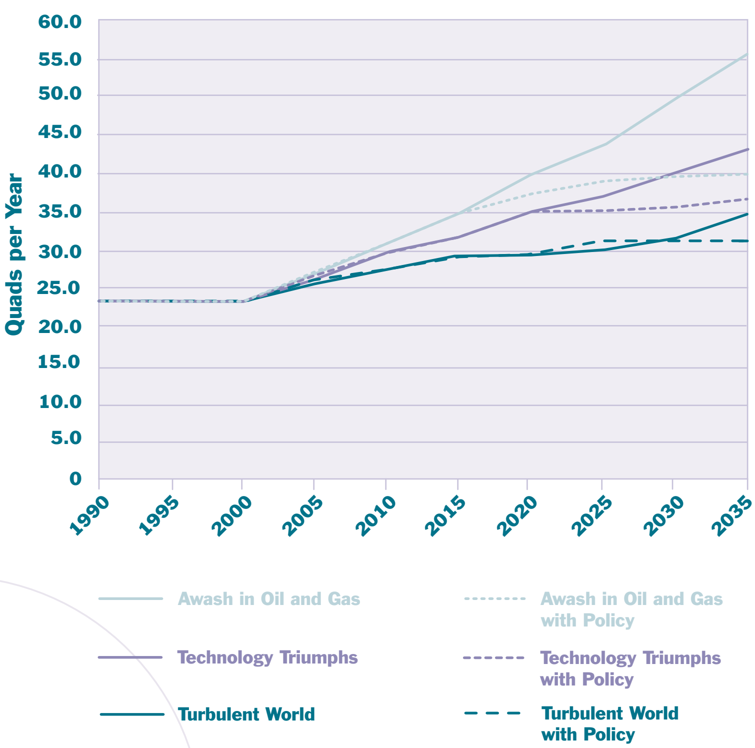
Natural Gas

One of the major factors contributing to the declining carbon intensity of the energy sector in all of the cases is the substitution of natural gas for coal and other fuels. Natural gas releases approximately one-half the CO_2 emissions of coal, per unit of energy supplied. The commercialization of advanced high-efficiency, low-emission, combined-cycle gas turbines dramatically increases the cost-competitiveness of natural gas in the electricity sector. In addition, as the technology for producing hydrogen from natural gas matures, hydrogen derived from natural gas begins to penetrate the market for transportation fuels. Figure 12 illustrates the trajectory of expanding natural gas demand in the three base case scenarios and their respective policy overlay cases.

Natural gas demand roughly doubles from 24 Quads in 2000 in both the *Awash in Oil and Gas* base case (to 55 Quads) and in *Technology Triumphs* base case (to 43 Quads).[20] In the *Turbulent World* base case, natural gas consumption increases to nearly 35 Quads in 2035. In *Awash in Oil and Gas with Policy,* demand rises rapidly during 2000 to 2015 as new frontier gas fields are brought on-stream, then grows more slowly, and levels off at about 40 Quads in 2035. In *Technology Triumphs with Policy,* growth in natural gas demand is more moderate, reaching about 37 Quads in 2035. By comparison, in *Turbulent World with Policy,* with greater uncertainty about foreign supplies and without major development of Arctic or other frontier gas, natural gas demand reaches 31 Quads in 2035.

Figure 12

Total U.S. **Natural Gas Consumption**



Nuclear Power

Nuclear electricity supply varies by assumption across the Pew Center scenarios (see Figure 13). None is a high-nuclear case and none reflects a shutdown of the commercial nuclear industry. In both *Awash in Oil and Gas* base case and its policy overlay case, nuclear electricity supply declines by about 10 percent from 2000 to 2020 and then declines at a further rate of 1 percent per year. By 2035, nuclear generation falls to the thermal equivalent of about 4.5 Quads per year. In the *Technology Triumphs* base case and its policy overlay, U.S. nuclear power output remains constant from 2000 to 2035, with retirements of aging facilities just offset by improvements in the operational efficiency (and up-rating of capacity) at remaining plants and the introduction of a few advanced reactor units at existing nuclear sites. In *Turbulent World*, nuclear electric output first increases by about 5 percent from 2000 to 2020, as new smaller, advanced reactor designs are put into service. Then, following a terrorist incident in 2010, public acceptance of this technology declines, and output falls to approximately 5 percent below the year 2000 levels, as electric generating companies decide not to replace retiring reactors with new nuclear power plants. The simulated climate policy does not alter the outcome for nuclear power between any of the base case scenarios and their respective policy overlay cases, but other scenarios are possible.[21] (Also see Advanced Nuclear Technology Assessment in Appendix B.)

Figure 13

Nuclear Electricity Supply

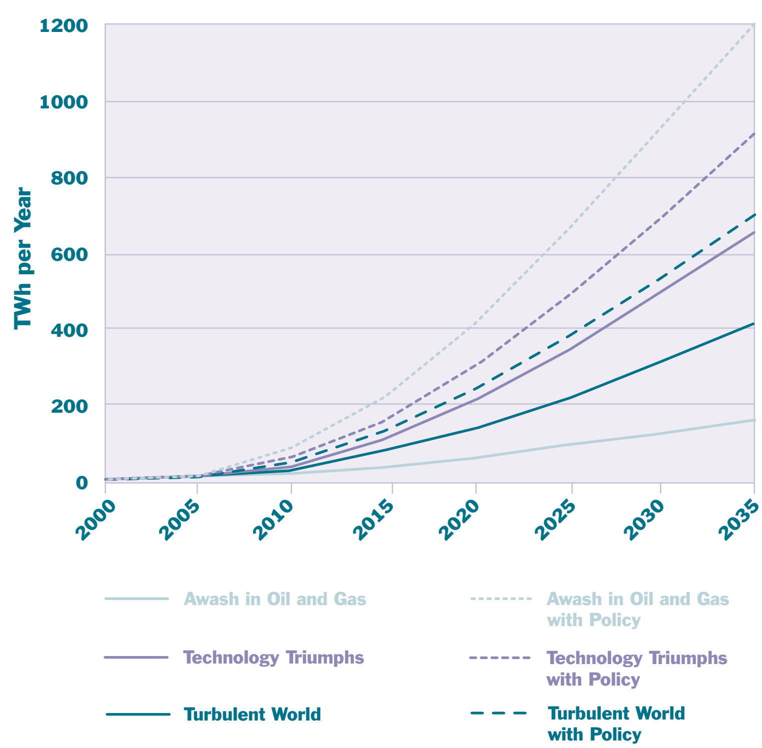
Renewable Energy

Additional factors contributing to the variation in carbon emissions among the cases include the rates of market penetration by renewable energy technologies and the commercial success of DG in the electricity sector. Figure 14 shows renewable energy use increasing in each of the three scenarios and their respective policy overlays. In *Awash in Oil and Gas,* concerns about local air pollution and the need to increase reliance on domestic resources drive a small investment in renewable energy technologies, but these technologies remain limited to niche markets, unable to compete with low coal prices and moderate gas prices. In *Technology Triumphs,* legislative measures such as state-level renewable portfolio standards, multi-pollutant regulations, national interconnection standards, and net metering combine with engineering advances and increased consumer demand to boost renewable energy technologies into the mainstream. In *Turbulent World,* federal concerns about energy facility security combine with eroding consumer confidence in large, conventional, centralized technologies to cause something of a renaissance of interest in solar, wind, and other renewable energy technologies, although not to the same extent as occurs in *Technology Triumphs.*

In all three policy overlay cases, investment in renewable energy technologies increases dramatically as part of a broad effort to reduce carbon intensity in the energy sector. This expanded investment substantially accelerates the commercialization and increases the contribution of renewable energy from 2010 to 2035. Among renewable energy technologies (other than large-scale hydroelectricity), wind makes the largest contribution to electricity production, followed by photovoltaic power systems. Figure 14 illustrates the combined contributions of wind, solar, and biomass energy technologies by scenario.

Figure 14

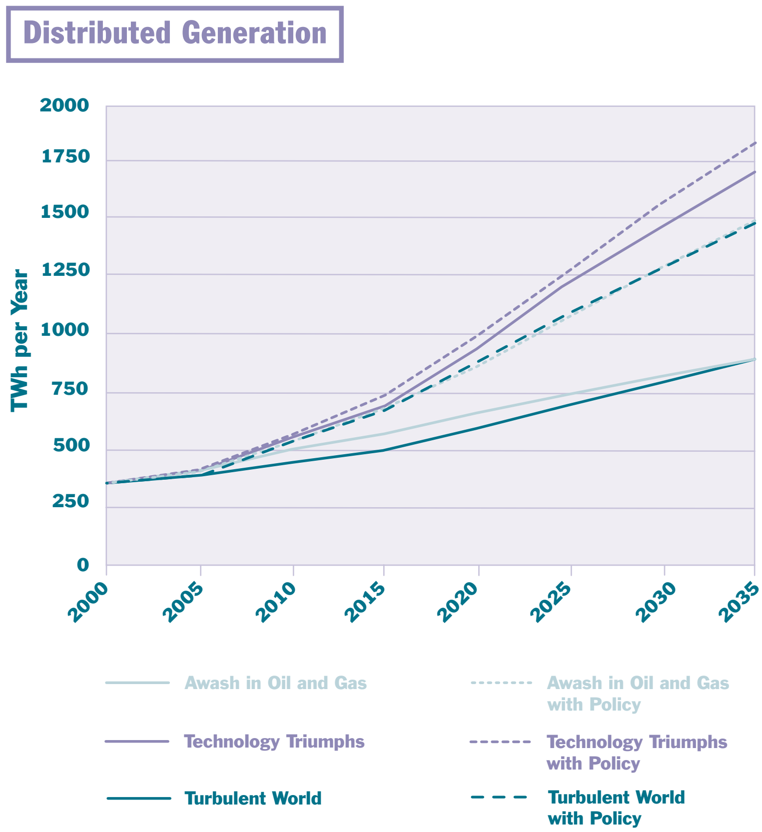
Renewable Electricity Supply



Distributed Generation

DG is driven by many of the same factors that accelerate the commercialization of renewable energy technologies. The principal competitive advantage of DG derives from the reliability benefits and from the ability to obviate or defray the need to make capital investments in distribution infrastructure. For the purpose of this scenario planning exercise, DG is understood to include on-site solar, distributed wind power, and on-site combined heat and power installations (including those incorporating natural gas-fired turbines, diesel engines, and stationary fuel cell power systems). Figure 15 illustrates the market penetration of DG technologies across the scenarios (see DG Technology Assessment in Appendix B).

Figure 15



Progressive state policies, private investment, consumer demand, and engineering advances encourage the use of DG in *Technology Triumphs,* whereas in *Awash in Oil and Gas,* the much smaller increase in DG use is driven mainly by customer demand for enhanced reliability and federal efforts to promote the use of domestic resources. In *Turbulent World,* DG is used principally in on-site applications in the commercial sector, in gated residential communities, and in industrial cogeneration applications. In all the policy overlay cases, policies to reduce carbon emissions rapidly accelerate the commercialization of DG technologies.

Hydrogen Production and Use

The development and commercialization of hydrogen as a fuel is an important element in all of the cases (see Hydrogen Technology Assessment in Appendix B). In the base case scenarios and in the policy overlay cases examined in this exercise, hydrogen is used primarily in fuel cells, for both mobile and stationary applications. The costs of delivering hydrogen in these scenarios are assumed to be \$22 per MBtu in *Technology Triumphs* and \$25 per MBtu in *Awash in Oil and Gas* and *Turbulent World.* In the policy overlay cases, the combination of the hydrogen production tax credit and the hydrogen infrastructure investment tax credit reduce the delivered cost by $3 per MBtu. Figure 16 illustrates the level of hydrogen production for all the cases.

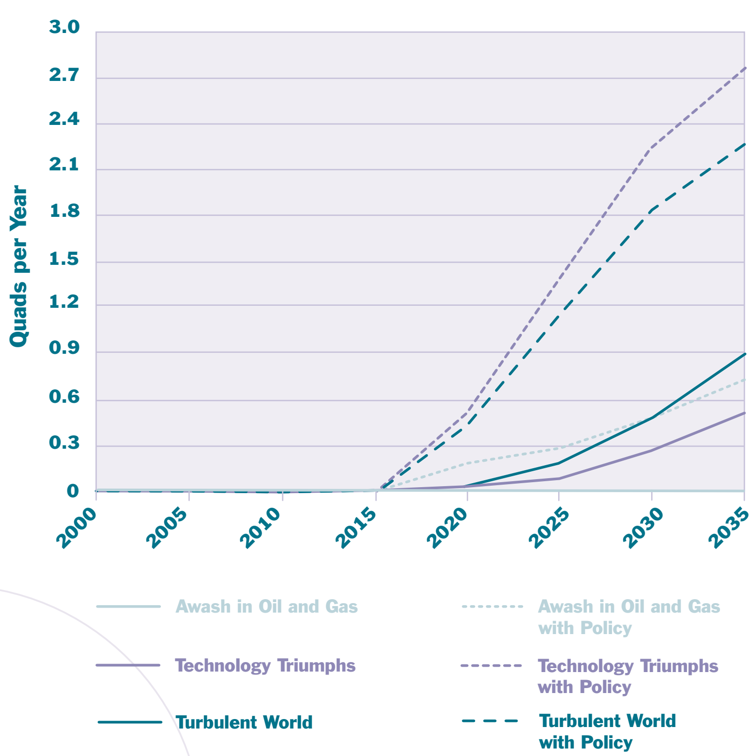
A small amount of hydrogen is produced commercially in the United States today, mainly for on-site applications in the industrial sector. For hydrogen to become an important part of the U.S. energy economy, its production and distribution would need to increase from the year-2000 level by at least two orders of magnitude. Significant progress is made in that direction in each of the scenarios explored in this exercise, but across all the base case scenarios and their policy overlay cases, hydrogen represents less than three Quads per year, which is three percent or less of total primary energy in 2035.

The pathway to hydrogen production varies significantly among the scenarios. In the *Turbulent World* base case and its associated policy overlay, hydrogen is made almost entirely from domestic coal resources. In the *Technology Triumphs* base case and policy overlay, hydrogen is produced using a variety of production technologies. Natural gas accounts for about 80 percent of hydrogen production in *Technology Triumphs* in 2035. In *Technology Triumphs with Policy*, natural gas supplies the feedstock for 50 percent of hydrogen production in 2025 and about 35 percent in 2035. In this policy overlay case, 35 percent of the hydrogen in 2025 and 53 percent in 2035 is produced from coal. The coal contribution increases in this scenario as the production technology for extracting hydrogen from raw coal increases in efficiency and declines in cost over time. Hydrogen is also manufactured in the latter portion of the *Technology Triumphs* base case and policy overlay scenarios using renewable energy to break down water into hydrogen and oxygen by electrolysis. Renewable energy contributes 16 percent of the hydrogen in 2025 and 11 percent in 2035 to *Technology Triumphs with Policy.*

In the *Awash in Oil and Gas* base case, almost no hydrogen is produced from 2000 to 2035. In the policy overlay case, approximately 75 percent of the hydrogen is produced from natural gas, and 25 percent is produced using renewable energy.

Figure 16

Hydrogen Production



Sectoral Energy Use

The dynamics of the base case scenarios and the policy overlay cases affect the distribution of energy demand among major sectors of the economy between 2000 and 2035. The driving forces in these scenarios also affect the composition of demand in each sector. Oil use for transportation remains at approximately the year-2000 level in the *Technology Triumphs* and *Turbulent World* base case scenarios, but increases substantially in the *Awash in Oil and Gas* base case. By contrast, in 2035 transportation energy demand and oil use has declined in all of the policy overlay cases, as new car purchases shift toward more efficient vehicles, especially hybrids and fuel cell vehicles. Despite increased attention to energy efficiency, industrial energy demand increases in all scenarios, with most of the incremental demand captured by natural gas. From 2000 to 2035, economy-wide electricity use grows significantly in each base case scenario. In each of the policy overlay cases, increases in end-use efficiency keeps economy-wide demand for electricity close to the year-2000 level. However, the composition of electricity demand changes as the policy overlay cases unfold, with most new loads arising in the residential and commercial sectors.

Industry

In all the base cases, the U.S. economy continues to shift toward increasing dominance by the service sector. In *Awash in Oil and Gas* and *Turbulent World,* industry continues to value technologies that offer flexibility to respond to fluctuating prices, uncertainty in global markets, and changing circumstances. In *Technology Triumphs,* industry uses and improves techniques of mass customization to produce quality products that meet the varied demands of a discerning consumer. Also, industry increasingly relies upon energy service companies (ESCOs) as it seeks to become more efficient, both to improve profitability and to achieve a "green" image.

In the policy overlay cases, industry responds to the carbon constraint in numerous ways. In addition to outsourcing energy management, industrial firms take full advantage of programs to disseminate energy information, along with the removal of regulatory barriers, to become more energy efficient. An excellent example of this is the sharp expansion of CHP at large industrial facilities. In *Technology Triumphs with Policy,* large-scale industrial CHP rises to 773 TWh by 2035. This represents nearly a doubling of CHP output from the year 2000 level. The other two policy scenarios also see impressive increases in CHP penetration. Industry also takes advantage of a number of research and development financial incentives to speed the introduction of a range of energy-efficient and low-carbon products and processes.

Buildings

In Awash in Oil and Gas, *low energy prices combine with the demand for larger homes, as well as the increased use of electrical equipment in both residential and commercial applications, raising energy end-use demand in the buildings sector.* *Technology Triumphs* incorporates a similar but smaller increase in demand for electricity in buildings, due to the more rapid uptake of energy efficiency measures in this scenario. Additionally, in *Technology Triumphs,* “Smart House” software helps homeowners manage energy use efficiently and cost-effectively. BIPV systems become commercially viable earlier in this base case and are more widely used than in the either of the other two base case scenarios.

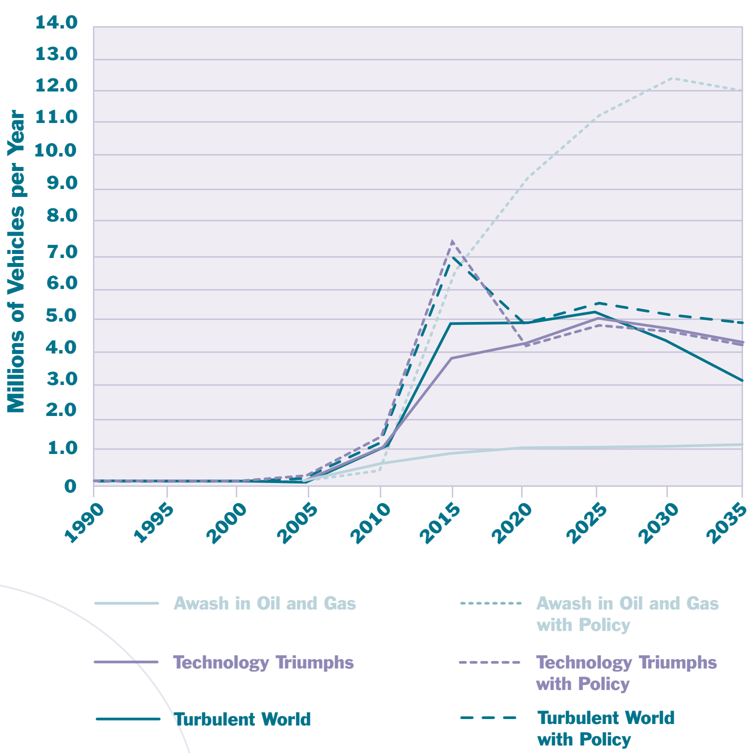
Performance standards accelerate efficiency improvements for electric appliances and gas- and oil-fired equipment in all three policy overlay cases. In addition, training programs for operating engineers in commercial buildings; information and marketing programs for building owners and businesses; and efficiency ratings for houses, appliances, and other major energy-consuming devices provide information to end-users and investors that help to lower the barriers to market penetration for cost-effective efficiency-improving measures.

Transportation

Transportation accounted for approximately 30 percent of U.S. CO_2 emissions in 2000. Variations in fuel prices along with differences in land-use policies and in patterns of urban development explain some of the variation in carbon emissions from transportation among the scenarios. Other important factors include the choices that consumers and companies make each year about new light-duty vehicle purchases.

Figure 17

Annual Purchases of New Hybrid Gasoline-Electric and Diesel-Electric Light-Duty Vehicles



Two of the key vehicle types that affect the rate of growth in carbon emissions from the transportation sector are hybrid vehicles (with either gasoline-electric or diesel-electric drive trains) and fuel cell vehicles. Cost-competitive hybrid vehicles establish the first significant market penetration for vehicles with electric drive trains and capture a significant market share at an earlier date than do fuel cell vehicles in all scenarios. Figure 17 illustrates annual purchases of hybrid gasoline-electric and diesel-electric light-duty vehicles.

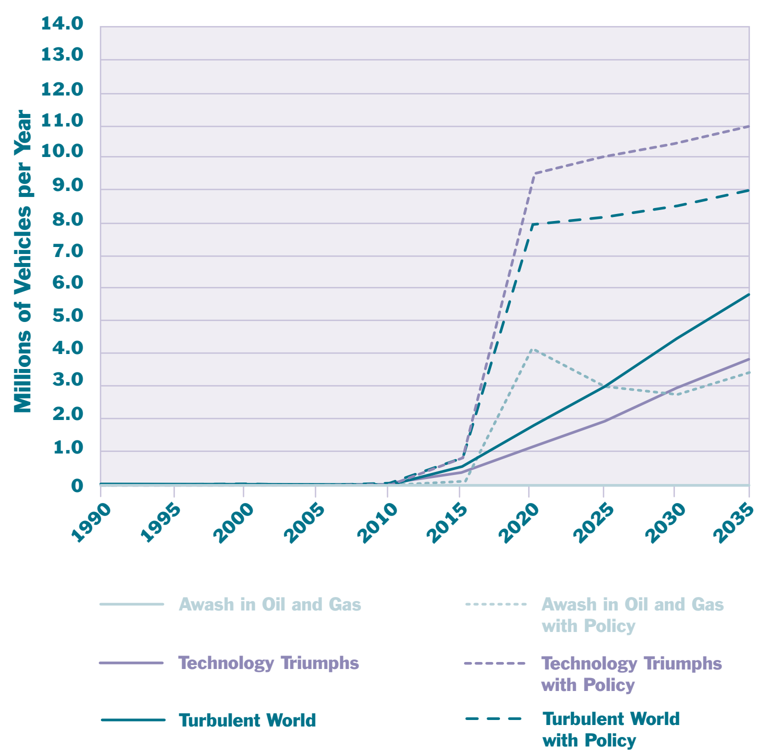
Hybrid gas-electric and diesel-electric vehicles first enter the U.S. market in 2000 and reach sales of approximately 1 million units per year (7 percent of new vehicle sales) by 2010 in *Technology Triumphs* and *Turbulent World.* In *Awash in Oil and Gas,* where oil is cheap and abundant and the United States is not worried about import dependence, hybrid sales reach this point in 2015 and then level off, whereas in *Technology Triumphs* and *Turbulent World,* sales of new hybrid light-duty vehicles accelerate rapidly to reach between 4 and 5 million units per year (25 percent of new vehicle sales), in 2015.

With a climate policy, hybrid vehicle sales grow even more rapidly. A CO_2 emission credit trading program for vehicle manufacturers translates into price reductions for consumers and increased sales for hybrid vehicles. The growth in hybrid car and truck sales peaks in 2015 and then falls off after 2025 in *Technology Triumphs with Policy* and *Turbulent World with Policy,* as consumers seeking safe, efficient transportation move increasingly into fuel cell vehicles (see Figures 17 and 18). Facing a very tight carbon constraint, hybrid vehicle sales continue to increase in *Awash in Oil and Gas with Policy* after 2020, peaking at approximately 12 million units per year (65 percent of new vehicle sales) by 2030.

Figure 18 illustrates the sale of fuel-cell vehicles from 2000 to 2035. Beginning in 2010, fuel cell vehicle purchases increase significantly in each base case scenario except *Awash in Oil and Gas.* In *Awash in Oil and Gas,* a world with low fuel prices, no carbon constraint, or any concerns about oil import dependence, fuel cell vehicles never catch on in the United States, and sales remain well below 100,000 units per year (less than 0.4 percent of new vehicle sales) through 2035. In *Turbulent World,* the impact of the national commitment to a "moonshot" program to promote development of fuel cell and hydrogen technology leads to fuel cell vehicle sales of 2 million vehicles per year by 2020. By 2035, the increased reliance on domestic fuel resources combines with the effect of the "moonshot" to push fuel cell vehicle sales to approximately 6 million units per year (33 percent of new vehicle sales) in *Turbulent World.* In *Technology*

Figure 18

Annual Purchases of New Fuel-Cell Powered Light-Duty Vehicles



Triumphs, private R&D and state-based initiatives like the California Fuel Cell Partnership stimulate fuel cell vehicle sales of more than one million new light-duty vehicles by 2020 and of four million by 2035 (22 percent of new vehicle sales).

In *Awash in Oil and Gas with Policy,* the need to meet a tight carbon constraint provides a major impetus for fuel cell vehicle sales, which reach 4 million units per year in 2020, falling back to about 3.5 million new car and light truck sales in 2035, as hybrid vehicles sweep the market. In *Turbulent World with Policy,* fuel cell vehicle sales take off in 2015, rising from one million units per year in 2015 to four million units per year in 2020 and reaching nine million new light-duty vehicle sales (or 53 percent market share) in 2035. But the most striking expansion of the market for fuel cell vehicles occurs in *Technology Triumphs with Policy.* In this scenario, sales of light-duty vehicles with fuel cell drive trains explode in 2015, increasing from one million units per year to 9.5 million new vehicle sales in 2020 and reaching 11 million new light-duty vehicles (or 59 percent market share) in 2035.

In each of the policy overlay cases, the introduction of advanced fuel-efficient vehicles dramatically reduces carbon emissions from the transportation sector in the latter half of the scenarios. Figure 19 illustrates the average on-road fleet efficiency of new light-duty vehicles in each scenario.

In *Awash in Oil and Gas,* low prices and a lack of concern for the impacts of continuing oil import dependence lead to the purchase of few energy-efficient vehicles; thus, average on-road efficiency for new light duty vehicles rises only about ten percent in 35 years, from 20 to 22 miles per gallon (mpg). In *Technology Triumphs,* by comparison, the effects of investments in new technology, state standards, and consumer interest converge to raise average on-road efficiency of new light-duty vehicles from 20 mpg in 2000 to about 40 mpg in 2035. In *Turbulent World,* on-road average fleet efficiency for new light-duty vehicles increases to over 45 mpg in 2035, mainly due to the effects of the tighter CAFE standards, the "moonshot," and the successful development of fuel cell vehicles.

Figure 19

Average On–Road Fleet Efficiency for New Light-Duty Vehicles

The most dramatic efficiency improvements are found in the three policy overlay cases. Driven by the need to meet a tight carbon constraint, and fueled by both private and public R&D investments, major strides are made in efforts to improve the fuel efficiency of light-duty vehicles. In the three policy overlay cases, the on-road average fleet efficiency of cars and light trucks increases from 20 mpg in 2000 to between 55 and 65 mpg in these scenarios. This dramatic increase in on-road average fleet fuel efficiency is the major contributor to emissions reductions in the transportation sector.

Energy Security

Energy security is one of the critical issues facing the United States in the period from 2000 to 2035. For the purposes of this study, the energy security issue has been divided into two components—dependence of the U.S. economy on imported fuels, and the vulnerability of critical energy facilities to disruption by accidents or terrorist acts.

Import Dependence

The evolution of the transportion sector is an especially important factor in determining the level of U.S. oil demand and the consequent degree of dependence on foreign sources. In *Awash in Oil and Gas,* abundant availability and historically low prices lead to increasing levels of net crude oil and petroleum product imports throughout the scenario period, reaching approximately 42 Quads in 2035. This is equivalent to approximately 70 percent of total U.S. petroleum demand in this scenario. In the other base case scenarios and in all of the policy overlay cases, net oil imports peak in 2010 and decline steadily (though at different rates) to 2035 (see Figure 20).

In *Turbulent World,* net oil imports peak at about 28 Quads in 2010 and fall to approximately 20 quads in 2035, or 16 percent below their year 2000 level. Even at this level, in 2035 the United States still relies on net oil imports

Figure 20

U.S. Imports of Crude Oil and Petroleum Products

to fill approximately 60 percent of U.S. petroleum demand. In *Technology Triumphs,* net oil imports peak in 2010 as well (at about 29 Quads), but only decline to 23 Quads in 2035. In this scenario, the high fuel efficiency and growing popularity of hybrids and fuel cell vehicles is partly offset by the increased driving that occurs with higher incomes.

Figure 20 also shows the effects of the carbon constraint on oil consumption and imports in the policy overlay cases. When the climate policies are imposed in 2010 (and as they begin to bite), the rising cost of fuel reduces demand for imported fuel. As Americans shift to more fuel-efficient vehicles in the policy overlay cases, they are able to maintain personal mobility while dramatically reducing oil demand in the transportation sector.

Another important aspect of oil import dependence that affects national security is the level of U.S. expenditures on imported oil. Figure 21 illustrates the trajectory of U.S. energy expenditures for imported oil and petroleum products by scenario.

Figure 21 highlights the scale of the drain on the U.S. economy associated with paying for oil. In 2000, payments for oil imports cost approximately $125 billion. In *Turbulent World,* the period 2005 to 2010 is marked by chaotic politics in the Middle East and a string of oil supply interruptions. Between 2005 and 2010, oil prices double relative to their year 2000 level, causing U.S. expenditures for imported oil to also double, reaching nearly $300 billion in 2010. These huge transfers of dollars drive the federal government to place major policy emphasis on improving energy efficiency and shifting to coal-based hydrogen in the transportation sector.

For comparison, in the three policy overlay cases, imposition of climate policies has an important salutary effect on oil imports and on expenditures to pay for those imports. By 2035, the shift to fuel-efficient vehicles along with other energy-efficiency improving technologies reduces U.S. expenditures on net oil imports by $50 to $80 billion

Figure 21

Expenditures on Oil Imports

per year, relative to the historic levels in 2000. From this standpoint, the benefits of reduced oil imports outweigh the costs of investments in energy efficiency, with a resulting positive impact on the economy.

Security of U.S. Energy Facilities

The vulnerability of U.S. energy facilities to disruption by accidents or terrorists is another component of energy security. This aspect, like the larger question of homeland security in general, is much more complex than the issue of U.S. dependence on imported fuels. Energy facility security comes into each scenario in different ways.

In both the *Awash in Oil and Gas* base case and its policy overlay, there is little concern among public policymakers about terrorist incidents at U.S. energy facilities. In this scenario, the 2000 to 2035 period is an interval of calm and cooperative trade relations with political tranquility worldwide. Oil and gas prices are at historically low levels, supplies are abundant, and foreign governments look for opportunities to cooperate with U.S. policies. By contrast, in the *Turbulent World* base case and its policy overlay, security of energy facilities is a major concern for public policymakers and private investors. A terrorist incident at a U.S. nuclear power plant in 2010 leads to a significant tightening of security regulations for all facilities that use, process, or handle nuclear material. Public sensitivity about potential risks from terrorists extends to many large energy facilities, increasing community resistance to the construction of new plants, even when scientific studies suggests that the probability of dangerous events is extremely small.

In the *Technology Triumphs* base case scenario and its policy overlay case, the risks to energy facilities are minimized by the shift toward increasing reliance on small, decentralized facilities, many employing renewable energy technologies. Nonetheless, there is a public perception of residual risks at many legacy plants, including nuclear power stations, chemical plants, waste treatment facilities, and natural gas pipelines. These perceived risks are largely ignored by the federal government but addressed at the state level through requirements for rigorous siting assessments on all proposed new plants and comprehensive security reviews for all existing facilities.

Fear of terrorist incidents is a major driving force behind public resistance to new energy facilities and catalyzes many NIMBY protests. Concerns about energy facility security and the potential role of terrorists in the energy sector plays a supporting role in motivating the move to DG technologies, renewable energy systems, and many other small-scale, decentralized systems that emerge as alternatives to large, conventional centralized energy facilities.

IV. Conclusions

This study presents a set of scenarios describing three divergent paths for the United States from 2000 through 2035. Many different patterns of energy supply and use could emerge in the future. The scenarios presented here reveal important conclusions about the role of technology in determining future U.S. energy supply, energy demand, and carbon emissions. These scenarios are not predictions; taken together however, they can be used to help identify key technologies, important energy policy decisions, and strategic investment choices that can increase the likelihood of achieving U.S. energy security, environmental protection, and economic development goals across a range of possible futures. Taking these lessons into account can help decision-makers plan for the future, despite uncertainty about how the future will unfold.

This exercise takes three different base case scenarios and analyzes the implications of imposing the same portfolio of policies on each of them. This approach allows conclusions to be drawn about the relative difficulty of implementing a carbon-constraint policy under quite different conditions. External events and other driving forces vary widely among the scenarios, as do policy and investment decisions and the consequent paths of technology development. Some conditions, such as low fossil fuel prices, increase the difficulty of implementing a carbon constraint. In contrast, actions such as early and sustained investment in emerging energy technologies facilitate both domestic economic development and carbon emissions reductions. Taken together, the three policy overlay cases show that a portfolio of market-oriented policies and standards can lead to substantial reductions in U.S. CO_2 emissions by 2035, without major negative impacts on the overall level of U.S. economic activity. However, implementation of such policies could have significant costs for the energy and energy-intensive sectors of the economy.

Without a mandatory carbon constraint, the absolute level of emissions rises in each base case scenario, despite the fact that the carbon intensity of the economy declines considerably. In the Pew Center scenarios without a carbon emissions policy, CO_2 emissions in 2035 range from 1800 to 2400 MMTC, an increase of 15 to 50 percent over the U.S. year 2000 level. This result points to the need to develop climate change policy in order to stem these increases.

The scenario analysis identified several technologies as critical to the U.S. energy future in a carbon-constrained world. These technologies are beneficial across scenarios, though the relative importance of a particular technology may vary among the scenarios. Most of these technologies would have a place even in a world without a carbon constraint, as they assist the United States in achieving its policy objectives—including environmental and energy security goals—while growing the economy.

Natural gas is one of the most important contributors to the decline of the carbon intensity of the energy sector in both the base and policy overlay cases. The market for natural gas expands in all scenarios, with and without the policy overlays. Substituting natural gas for coal results in approximately half the carbon emissions per unit of energy supplied. Increased use of natural gas also has energy security benefits for the United States.

Energy efficiency improvements also play a key role in reducing carbon emissions. In response to the carbon constraint, the fuel economy of cars and light trucks dramatically improves in the policy cases, significantly reducing oil imports. In each of the scenarios, combined heat and power technology improves the efficiency of electric generation. When the carbon policy overlay is imposed, performance standards for electrical devices and for gas- and oil-fired equipment lead to improved energy efficiency in the residential, commercial, and industrial sectors.

Renewable energy and distributed generation technologies contribute to the reduction of carbon emissions in each of the scenarios and their policy overlay cases. While both renewable energy technologies and DG grow in the base case scenarios, they experience more substantial increases following the implementation of the policy overlay, which aids their commercialization by promoting investment and by breaking barriers to entry in U.S. energy markets.

Nuclear power plays a significant role in each of the scenarios and their associated policy cases. Nuclear power production remains close to the year 2000 level in each scenario, with and without the policy overlays. In the absence of nuclear power, carbon emissions would be significantly higher in 2035.

Geological sequestration emerges as a key technology in the policy overlay cases, allowing continued reliance on fossil fuels even in the face of a carbon constraint. Sequestration is particularly important in *Turbulent World with Policy,* a scenario in which hydrogen is produced primarily from coal. Geological sequestration allows hydrogen to be produced from fossil fuels without releasing carbon emissions, facilitating the transition to a hydrogen economy.

Hybrid-electric vehicles play an important role in the transportation sector for all cases, except the *Awash in Oil* base case, and act as a bridge technology for fuel cells in mobile applications. Toward the end of the scenario period, hydrogen and fuel cells become significant in *Technology Triumphs with Policy* and *Turbulent World with Policy.* As improvements in energy efficiency slow, the technology for hydrogen and fuel cells matures in these scenarios, accounting for an increasing share of economy-wide carbon reductions.

Many of these critical technologies, however, are not commercially viable in 2003. Public and private investment in these emerging energy technologies plays a key role in their successful commercialization in the Pew Center scenarios. Public policies at the state and federal level are necessary to lower barriers to commercialization of these technologies and to stimulate sustained investment during the course of these scenarios. Included among the policies that promote commercialization of these technologies are a carbon emissions allowance cap-and-trade program for some sectors and a set of equipment-efficiency credit trading programs, as well as renewable portfolio standards, fuel economy and air quality requirements, and electric power grid interconnection standards.

One key insight that emerged is that policy is necessary to address climate change. A second is that there are technologies—with supporting policies and investments—that could address climate change, accelerate capital stock turnover, and enhance the nation's energy security, no matter which direction the future takes. Finally, the scenarios indicate that energy policy and investment decisions made today affect the difficulty of implementing a climate policy tomorrow. If U.S. decision-makers can implement the necessary policies and encourage appropriate investments during the next thirty years, the United States could be better positioned to achieve its complementary economic, energy security, and environmental goals.

Endnotes

1. U.S. population grows at an annual average rate of 0.82 percent per year. Depending on the scenario, GDP grows at an average annual rate of 2.4 to 3.0 percent per year.

2. One BTU is equivalent to the energy required to raise the temperature of one pound of water by one degree Fahrenheit (1 F°). One Quad is an amount of energy equal to 10^{15} (or 1 Quadrillion) BTUs. This amount of energy is approximately equivalent to 1.08 X 10^{18} Joules (i.e., 1 exajoule or 1 EJ) and represents the aggregate average annual energy consumption of approximately 2.8 million Americans.

3. One million metric ton of carbon (1 MMTC) is equivalent to 3.67 million metric tons of carbon dioxide (CO_2).

4. Power quality refers to having fewer transients (short spikes in voltage), less electromagnetic interference, fewer harmonics that distort voltage, and fewer voltage sags and swells.

5. Key assumptions include the opportunities for cost-effective energy efficiency improvements and how decision-makers take advantage of these opportunities. Key aspects of the model structure include the level of technological detail and the way GDP is calculated.

6. The Pew Center's economics program is undertaking a separate multi-year effort to improve best practices in economic modeling and generate projected costs of actual policy proposals.

7. Unless otherwise noted, all monetized quantities are given in constant year-2000 dollars.

8. This legislation limits the financial exposure of the nuclear industry to accidents and other risks at commercial nuclear power plants to a maximum of $10 billion per plant. Beyond this cap, the federal government would assume the exposure. To date, the federal government has never incurred any actual costs related to the Price-Anderson Act

9. However, there is a broad range of estimates of future capital costs for nuclear power plants in the literature.

10. Tariff policy is a way to standardize the amount that utilities charge on-site generators for electricity and pay to those generators for electricity that is generated on-site and contributed to the utility grid.

11. Net metering is a technique that allows a facility certified to generate electricity on-site and provide it to the utility grid to subtract the amount of energy that the site puts into the utility grid from the amount which is drawn from the grid, paying only for the difference between the two quantities.

12. In some jurisdictions, local utilities will purchase electricity generated by on-site producers if the on-site facility produces more electricity than is needed to meet on-site demands.

13. Weyant J. and J. Hill (Eds.) (1999). "The Costs of the Kyoto Protocol: A Multi-Model Evaluation." *The Energy Journal*, Special Issue.

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14. Weyant and Hill, 1999.

15. Edmonds et al, 1999, pp. 13-16.

16. Reilly et al, 1999; Reilly et al 2003, p. 31.

17. McCarl and Schneider (2001).

18. U.S. EIA, Annual Energy Outlook 2002, Report DOE/EIA-0383(2002), U.S. Energy Information Administration, December 2001.

19. The Pew Center's economics program is currently undertaking efforts to evaluate the costs and benefits of climate policy that will incorporate a more complete range of flexibility in both modeling assumptions and policy choices.

20. Reports available in the open literature indicate that analysts disagree on the size of low-cost North American gas reserves and on the future price path for natural gas. Some analysis suggests that reaching levels of natural gas supply in the range of 50 quads per year from continental sources in North America will require the development of new and unconventional supplies including gas in tight formations and substantial quantities of coal bed methane or the expansion of liquefied natural gas (LNG) import facilities.

21. Scenarios with lower nuclear capital costs, or opportunities for producing hydrogen from nuclear power, are possible but were not considered in this exercise.

Note: Endnotes 22-42 can be found with Technology Assessments in the web version at www.pewclimate.org.

Appendix A: Glossary

Balance-of-system – structures, power conditioning equipment, local control devices, and energy storage technology associated with PV and wind system installations

BELC – Business and Environment Leadership Council

BIPV – building-integrated photovoltaic

Brownfield – an existing industrial site

Btu = British thermal unit

CAFE – corporate average fuel economy

CCGT – combined cycle gas turbine

CHP – combined heat and power

CO_2 – carbon dioxide

DG – distributed generation

Energy intensity – amount of energy consumed per unit of GDP

ESCO – energy service company

FERC – Federal Energy Regulatory Commission

GBN – Global Business Network

GDP – Gross Domestic Product

GHG – greenhouse gas

Greenfield – an area free of industrial structures

GW – gigawatt

ICE – internal combustion engine

IGCC – Integrated gasification and combined cycle

Insolation – sunlight intensity

kW – kilowatt

kWh – kilowatt-hour

mcf – thousand cubic feet

MMTC – million metric tons carbon equivalent

NAS – National Academy of Sciences

NIMBY – Not In My Backyard

OPEC – Organization of the Petroleum Exporting Countries

PEM-FC – Proton-exchange membrane fuel cell

PV – photovoltaic

Quad – quadrillion British thermal units

RPS – renewable portfolio standard

RTO – Regional Transmission Organization

SUV – sport utility vehicle

TWh – Terawatt–hour

Unconventional gas – coal-bed methane, tight gas sands, shale gas

VMT – vehicle miles traveled

WTO – World Trade Organization

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This report discusses three possible future energy scenarios for the United States: *Awash in Oil and Gas, Technology Triumphs*, and *Turbulent World*. The Pew Center on Global Climate Change was established by the Pew Charitable Trusts to bring a new cooperative approach and critical scientific, economic, and technological expertise to the global climate change debate. We continue to inform this debate through wide-ranging analyses that add new facts and perspectives in four areas: policy (domestic and international), economics, environment, and solutions.

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