ELECTRIC POWER RESEARCH INSTITUTE

Program on Technology Innovation: Electric Power Research Institute – Electric Power Industry Technology Scenarios

Preliminary Results

Technical Report

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PRODUCT DESCRIPTION

This report describes the development of a set of scenarios for the future of the U.S. power industry. The scenarios were developed to provide a basis for strategic technology planning. The scenario approach was adopted in this initiative because scenarios provide insight on quantitative assessments and functional specifications of technologies. In contrast, standard planning tools—including the Electricity Technology Roadmap currently used at EPRI—are subject to the uncertainties in key driving factors, such as the economy, the environment, technology advances, and regulatory policies.

Results & Findings

Users of the report will gain an improved understanding of the economic and environmental factors that are likely to shape the structure of the industry and the changing business models of market entrants. Users also will be able to develop their own scenarios to address their individual needs and conduct sensitivity studies showing how varying key parameters can influence the outcomes of these analyses. This type of analysis is becoming increasingly valuable as the industries expand and as entrants with different perspectives evolve their own strategies.
The report identifies a set of ten specific technology opportunities that emerged from workshops that were part of the scenario process. The report describes these opportunities at a high level. Follow-on work is planned to define a detailed strategy for developing the technologies.

Challenges & Objective(s)

This report will benefit utility executives and planners, industrial and commercial electricity consumers, equipment suppliers, regulators, technology developers, national laboratory researchers, and academics. These stakeholders will benefit from a greater understanding of the issues and opportunities facing the electricity industry. The scenarios will facilitate communications among these groups and will provide a basis for collaboration among stakeholders to develop key technology opportunities.

Applications, Values & Use

Anticipated future developments include periodic revisiting of the issues raised in the scenario study and revising/updating the scenarios to reflect changes in the industry and externalities. Thus, the scenario study will be an evergreen document that will maintain its relevance, even as the external world changes dramatically.

EPRI Perspective

Scenario planning is a valuable tool for describing and analyzing possible future changes in the power industry. Its value derives from the ability to shape arguments and conclusions and to define alternative environments in which decisions can be modeled and played out. For the special case of defining research initiatives, scenario analysis can allow decision-makers to consider strategic adjustments in advance of changing conditions in uncertain environments. This capability is particularly valuable in the case of the power industry because of the rapid evolution of technology for the generation, transmission, distribution, and end uses of electricity. As change accelerates, uncertainty grows. Here, scenarios come into their own as a means of prioritizing alternate technologies and developing a portfolio of technologies.

Approach

The project team's goals were to

- document the process used to develop the scenarios,
- provide a detailed description of each scenario,
- identify the technology portfolio of each scenario, and
- determine the challenges and capability gaps that prevent the industry from achieving needed technology breakthroughs.

Keywords

Scenarios
Technology strategy
Energy efficiency
Electricity generation
Coal
Natural gas
Nuclear power
Renewables
Electricity transmission and distribution
Environment
Energy storage
Distributed generation
End-use technologies

EXECUTIVE SUMMARY

The *Electric Power Industry Technology Scenarios* project involves two major new thrusts:

1. It focuses the principal planning effort on the time horizon of 10–20 years, instead of the 50-year horizon of the current *Electricity Technology Roadmap* planning effort.
2. It uses scenario planning as a tool for explicitly incorporating the uncertainty inherent in any planning process.

The project involved three main steps:

- Define the scenarios by identifying the key industry drivers and establishing a view of future states of the world
- Identify the technology choices (literally a portfolio) that each scenario offers
- Determine the challenges and capability gaps that prevent us from achieving necessary technology breakthroughs.

The project began by identifying a key "focus" question about the future that the scenarios would address:

> How will demand for U.S. energy services and the potential externalities that may result shape electricity technologies over the next twenty years?

The four scenarios presented in this report are built upon two key uncertain drivers of change: the evolution of primary fuel markets, in particular natural gas that fuels the power sector, and changes in societal values on energy industry externalities, particularly carbon dioxide (CO_2). The four scenarios are depicted in Figure ES-1 and are described briefly below:

- **Digging in Our Heels.** Digging in our Heels is a world in which we actively resist change. Society embarks on a "momentum strategy". Natural gas and other primary fuel prices are rising, driven by growth in demand and supply constraints, and direct or imputed cost of CO_2 emissions is very low. This world may not be perfect, but the perceived cost of alternate strategies is deemed to be too high to receive attention.
- **Supply to the Rescue.** Supply to the Rescue is a world that relies on supply-side solutions to a broad range of energy issues. The abundant supply of low-cost natural gas in this world spurs economic growth and development, particularly in energy dependent businesses.

- **Double Whammy.** Double Whammy, as the name suggests, incorporates both high gas prices and high societal concerns about environmental costs. Taken together, these factors produce a more than proportionate share in their impact on the economy. Technology advances offer a collaborative basis for meeting the challenges of this world.
- **Biting the Bullet.** Biting the Bullet refers to the need to take painful actions in the near term to forestall even more painful consequences in the future. The climate change issues of Biting the Bullet have such a large impact on society that precipitous actions are required as society attempts to deal with a series of crises.

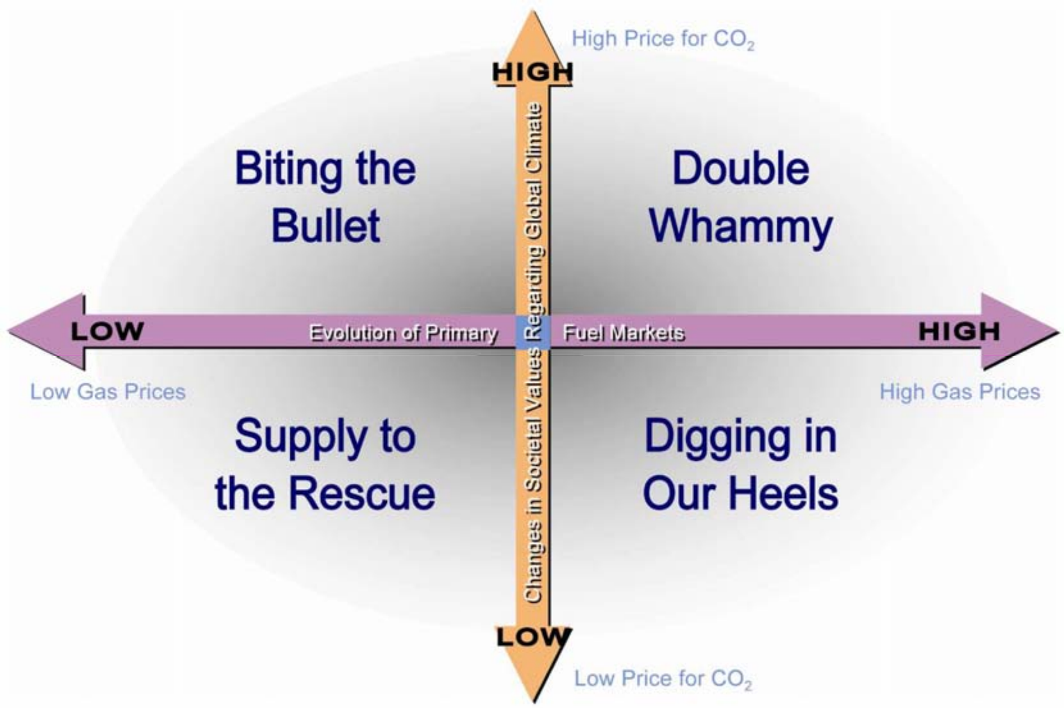

Figure ES-1
Depiction of EPRI Technology Scenarios

The results of this scenario analysis will be an input into the analysis supporting the next *EPRI Technology Roadmap*. To get a start at this, the robust and priority technology development areas presented below will be used.

1. **Customer Portal Investment.** The portal provides the physical and logical links that allow communication of electronic messages from the external network to consumer networks and intelligent equipment.
2. **Distribution Automation.** Integrated energy and communications system architecture; fault anticipation technology to forecast grid failures; adaptive islanding and storage technology.
3. **Carbon Capture and Sequestration.** Breakthrough technologies that reduce the economic impact of removing CO_2 from fossil generation plants; pilot-scale and full-size demonstrations of these advances.

4. **Advanced Coal and Nuclear Generation.** Low-emission designs of integrated gasification combined cycle (IGCC) generation for coal; demonstration of a stable licensing process and cost-effective deployment of advanced light water reactors; technology basis for the helium reactor.
5. **Environmental Emissions.** Control of a wide range of gaseous, aqueous, and solid pollutants that are produced as byproducts of electricity generation and use. Examples include SO_2, NO_X, fine particles, mercury compounds, and CO_2 for fossil generation.
6. **Energy Storage.** Large-scale, low-cost storage systems, focusing on advanced technologies such as flow batteries, flywheels, ultracapacitors, and compressed air energy storage.
7. **Transmission Portfolio.** Planning for expanding and enhancing the North American transmission grid; planning tools to assess the location, timing, and size of new power plants and transmission lines; integration of generation and transmission system upgrades.
8. **Sustain Existing Nuclear Fleet.** Application of reliability-focused technologies to resolve issues and manage assets; managing the transition to advanced light water reactors.
9. **Training and Simplification.** Develop and deploy tools for managing a power industry staffed with individuals who are not as well-trained as their predecessors.
10. **Sustain Existing Gas and Coal Fleets.** Advanced technologies for operating and maintaining the current fleet of fossil power plants, including asset management tools; address the need to meet emissions targets for these plants.

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1 INTRODUCTION

Background

For several years, the Electric Power Research Institute (EPRI) has developed and published the *Electricity Technology Roadmap*, a high-level document that provides guidance on strategic technology planning for the electricity industry. The *Roadmap* describes a global vision for electricity in the 21^{st} century, a plan to set strategic technological priorities, and an outline of the associated technologies needed to achieve the vision. The *Roadmap*'s goal is to encourage the debate, leadership, innovation, and investment that will enable electricity to realize its potential for increasing the quality of life on a global basis.

The time horizon of the *Roadmap* extends to 2050. We believe that it is possible to paint a vivid picture of the desired electrified world in 2050, and it is possible to describe in principle how one could access this end state through a combination of decades-long technology development efforts. However, quantitative assessments and functional specifications for such a distant future are problematic. Uncertainties in driving factors—such as the economy, the environment, technology advances, and regulatory policies—are large on the time scale of the *Roadmap* and do not provide sufficient granularity for the 10- to 20-year-ahead time frame.

To address this problem, we undertook this *Electric Power Industry Technology Scenarios* project. It involves two major new thrusts:

1. Focus the principal planning effort on the time horizon of 10–20 years, instead of the 50-year horizon of the current roadmap planning effort.
2. Use scenario planning as a tool for explicitly incorporating the uncertainty inherent in any planning process.

Taken as a whole, these initiatives allow for a probabilistic treatment of key future events and trends. In addition, the new approach will make the strategic plan better aligned with the processes used in the planning efforts of other organizations. However, the strong focus on emerging technologies in these "EPRI Scenarios" sets our initiative apart from the scenarios developed by others.

Description of Scenario Planning

Among the formidable challenges facing electric utility planners and executives and other electricity industry stakeholders are those of envisioning how future uncertainties will affect their individual technology strategies and related business plans. This includes how they will address operational uncertainties and prepare the strategic responses they will need for success. One way to meet these challenges is to create of a set of scenarios that project the potential outcomes of uncertain factors—without any attempt at prediction—and develop responses. Envisioning the future, developing strategic responses, comparing responses across scenarios, and building a robust strategy—these activities will help prepare for an uncertain future by developing the best strategies for success.

In the many applications, scenario planning has the ability to:

1. Organize perceptions about future alternatives
2. Remove biases in visioning
3. Focus debates about technology needs
4. Challenge the view that little will change
5. Enable development of alternative technology portfolios
6. Foster a probabilistic versus a deterministic view of the future

Scenario analysis begins by developing a set of alternate stories about how the world might develop. The scenarios are not predictions, but credible, challenging stories to explore "what if" and "how." The scenarios offer plausible resolutions to uncertainties in areas such as technology outcomes, market acceptance of innovation, the future state of the world, and the accrual of benefits in the scenarios. The scenarios should evaluate the benefits of future choices, if possible quantitatively. Each scenario should pose the questions: "If we found ourselves in this world, what areas of our business would be most affected? How would we respond?"

The EPRI Scenarios are not global societal scenarios trying to address all global issues and all sectors, but instead focus on the use of key drivers relevant to the electricity sector in the western world. EPRI elected to develop its own scenarios, rather than use scenarios of others, to provide a unique perspective on how technology advances can challenge the conventional wisdom of our energy future.

Objectives

1. Develop a set of scenarios that will enable systematic evaluations of the factors and variables that will shape the role of electricity in the future. These scenarios should address the needs and circumstances of all stakeholders in the electricity enterprise.
2. Use the scenarios to identify gaps in our understanding of technology's changing role in the power industry.
3. Develop a preliminary list of high-priority technology needs, with a focus on "robust" technologies that are valuable in more than one scenario.
4. Set the stage for a follow-on study to integrate the scenarios and technology gaps with the earlier work in the Electricity Technology Roadmap. This effort will define a more detailed technology development program for EPRI and the power industry, including deliverables, schedules, and costs.

Approach

The project involved three main steps:

- Define the scenarios by identifying the key industry drivers and establishing a view of future states of the world
- Identify the technology choices (literally a portfolio) that each scenario offers
- Determine the challenges and capability gaps that prevent us from achieving necessary technology breakthroughs.

We began by identifying a key “focus” question about the future that the scenarios would address:

> How will demand for U.S. energy services and the potential externalities that may result shape electricity technologies over the next twenty years?

In developing these scenarios, we considered a wide range of uncertain factors that can influence future developments. We discussed over 100 issues that might influence the evolution of the U.S. energy and electric power industries. We then grouped the issues into several overarching categories of key drivers. We determined that the following key drivers are both very important and uncertain and thus useful as the basis for developing scenarios:

1. The evolution of primary fuel markets
2. Changes in social values regarding energy externalities (like climate change)
3. The direction and structure of world economic growth
4. Changes in political values that influence regulations (priority of environmental issues)
5. Lifestyle and values shifts influencing consumer demand for energy services
6. The shape of the structure of the electric power industry (business models)
7. The course of natural events related to climate change
8. The course of price changes for electricity and consumer responses
9. The evolution of power industry infrastructure (decentralized or centralized).

Ultimately, we decided that the first two factors are the most critical and we used them to initiate scenario development. Figure 1-1 shows the matrix that grounds the scenarios. The matrix is built upon two key uncertain drivers of change: the evolution of primary fuel markets, in particular natural gas that fuels the power sector, and changes in societal values on energy industry externalities, particularly carbon dioxide (CO_2).

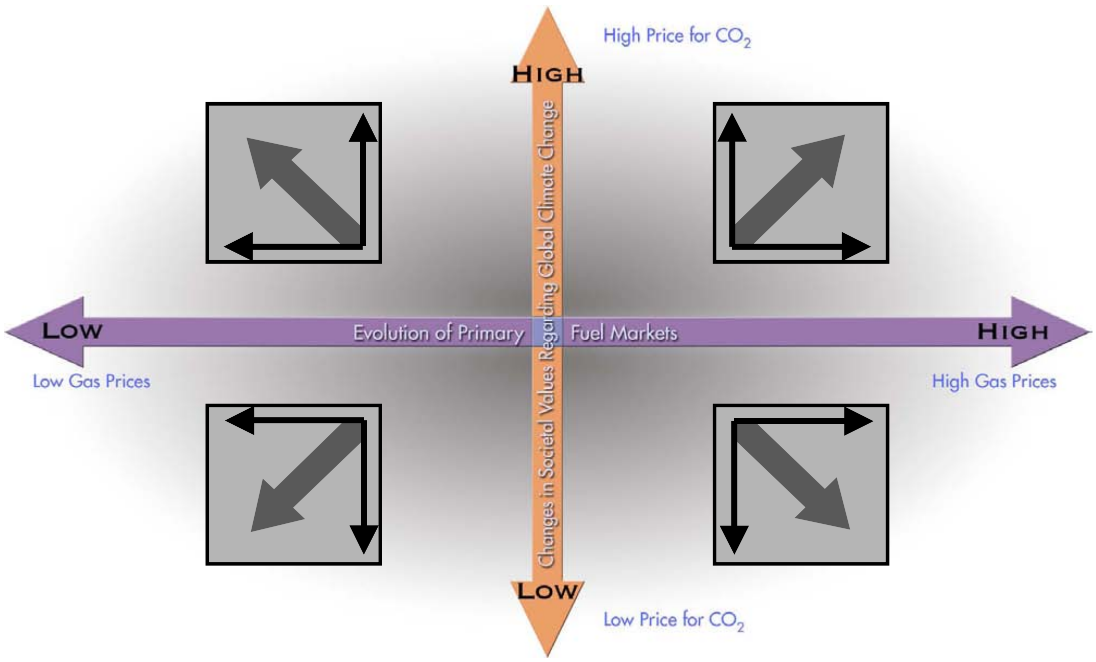


Figure 1-1
EPRI Scenario Matrix

Once we defined the matrix, we identified a set of starting assumptions (see Figure 1-2). The starting assumptions describe the current reality – a summary description of the key circumstances that are common to all the scenarios. These assumptions describe the scenario worlds as they are at the start of the scenario narratives.

We anticipate that the starting assumptions will have some staying power. While the assumptions may change over the course of the time horizon described in the scenarios, we anticipate that such changes will in most cases be relatively slow – evolutionary versus revolutionary.

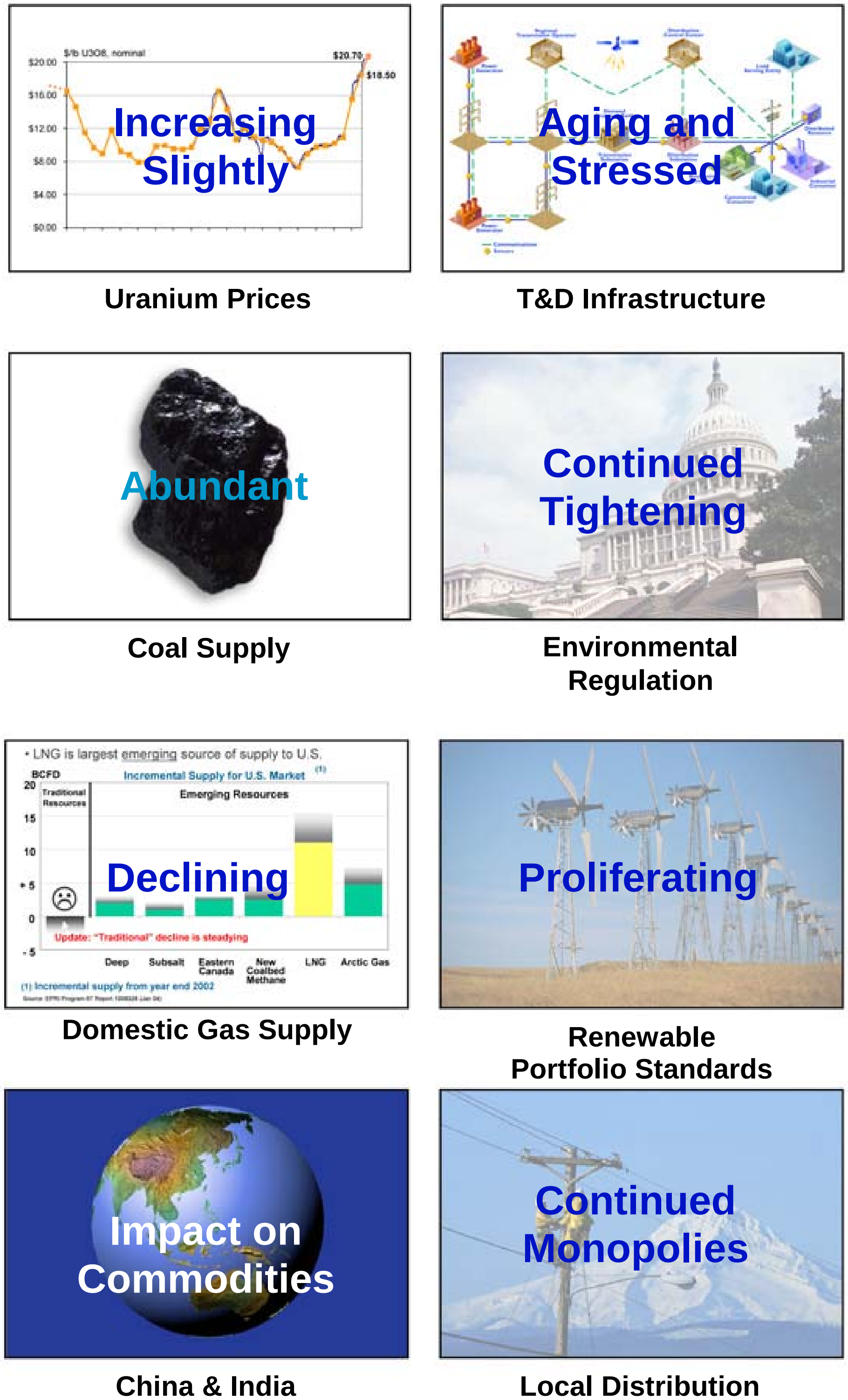


Figure 1-2
Starting Assumptions

Finally, we developed scenario descriptions and named them (see Figure 1-3). The scenario names provide a convenient shorthand for identifying the principal characteristics of the scenarios. The scenario descriptions should be considered "stories," not accurate predictions, of plausible future developments for the U.S. electric power industry over the next twenty years. The objectives of the scenario narratives (presented in Chapters 2 through 5) are to provide the rationale for the unfolding of possible events over time. The narratives are a tool to convey the core ideas of the scenarios.

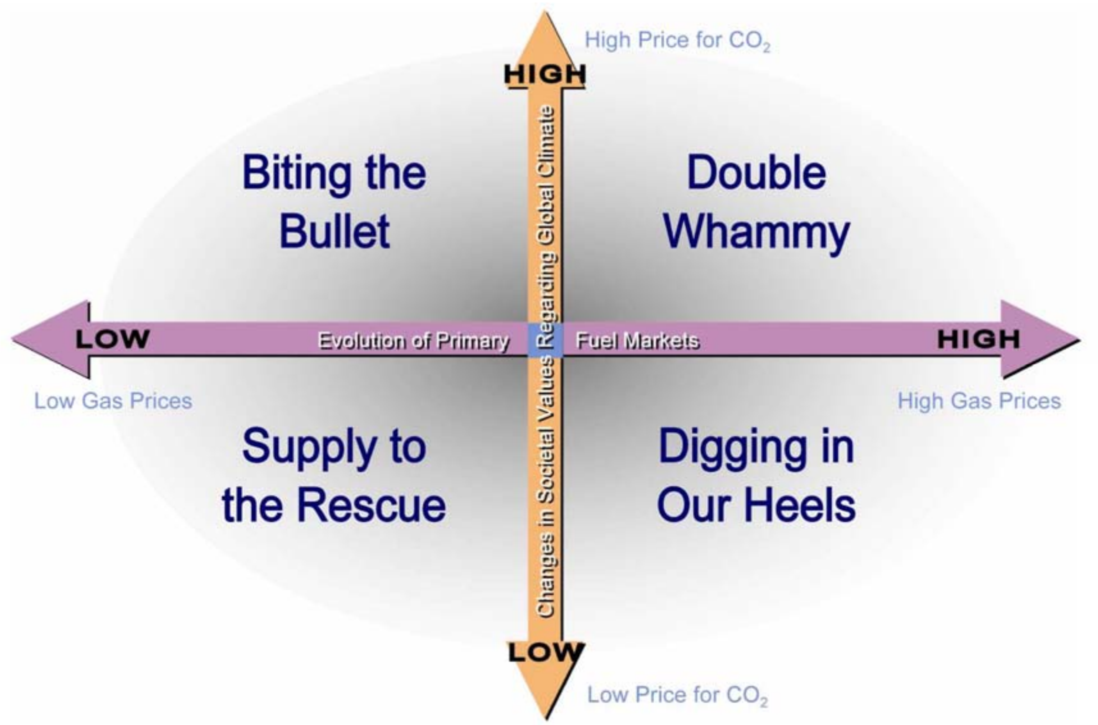


Figure 1-3
EPRI Scenario Names

2
DIGGING IN OUR HEELS

Digging in our Heels is a world in which we actively resist change. Society embarks on a "momentum strategy". This world may not be perfect, but the perceived cost of alternate strategies is deemed to be too high to receive attention.

In this world, natural gas and other primary fuel prices are rising, driven by growth in demand and supply constraints, and direct or imputed cost of CO_2 emissions is very low. The low cost of CO_2 derives from inconsistent political will and uncertainty regarding climate change, as well as the desire to avoid more significantly burdening the energy industry with the cost of mitigating its environmental externalities. This does not to imply that the environment is not an important concern of consumers—just that it is not a high priority.

This world, which evolves slowly from current conditions, reflects moderate to fast global economic growth and geopolitical circumstances in which the U.S., Europe, China, and India are the leaders. The U.S. digs in against imposing high cost on its economy to address what are perceived as unclear links between human activity and climate change. Many other nations, but not all, follow the U.S. lead. China and other developing economies, though using more modern and efficient technologies to fuel growth, make no extraordinary efforts to address climate change issues. They focus instead on wealth creation and poverty reduction. Global economic competition is driven by politics and concern for jobs more so than the level of energy and electricity prices. Energy price increases do not prevent long-term economic growth. U.S. labor productivity continues to grow, but wages are kept low because of competition from China and India, immigration, and reduced trade barriers in general.

Adequate energy supplies, though of some concern, are maintained because sufficient investment flows into resource development. Businesses and consumers accept increasing energy prices, even with a few shocks, since the value added in final energy consumption is high. The U.S. economy continues to shift toward a high-technology, service-oriented base with slow but steady increases in the adoption of energy-efficient technologies. Thus U.S. consumers maintain a high and growing standard of living.

But the power industry does not keep pace with the rest of the economy. Concerns for full cost recovery and tepid customer interest dampen plans by power companies to offer substantially higher-quality services or invest in new and replacement infrastructure—let alone advanced technologies. Central-station technology dominates decisions regarding new generating capacity at the expense of distributed generation. Gas and coal are the fuels of choice in the near term (2005 to 2015). New nuclear generation becomes increasingly competitive for a significant portion of the generation mix in the post-2015 time period. Reliability does not significantly improve and investments in the delivery infrastructure are limited to the basic level required to meet load growth, which tracks just below economic growth rates as energy intensity declines.

Figure 2-1 depicts key variables that describe the major dynamics of the scenario.

Figure 2-1
Overview of Digging in Our Heels

Full Scenario Narrative

2005–2012—Early Years

Some of the clearest signals about what may unfold over the next two decades in the electricity industry and related energy markets can be seen in the Energy Policy Act of 2005 (EPAct). Perhaps even more important than the law's specific provisions are what it says about political, social, and economic values and beliefs. The law was a compromise between those who think it will be easier to solve America's energy challenges by creating and finding more energy supplies and those who believe that pathways of non-emitting generation (renewable energy and nuclear energy), increased efficiency, and innovative technology will lead to security and sustainable development. Thus many see the new law as a punt. It does not raise the cost to the industry of addressing its externalities, essentially saying nothing about CO_2 cost. It makes only moderate steps to increase energy supplies, but not sufficient to reverse the trend in rising natural gas, oil, and other primary fuel prices. The slow evolution and implementation of this compromise legislation defines energy markets for the next two decades. Moreover, as this time period begins, it is unclear whether any monies will be available to fund the bill's provisions.

Within the U.S. electric power industry in 2005, conditions are just stabilizing from the disruptions caused by mixed results of industry restructuring and "de-regulation." The power industry is working through law suits, addressing excess generation in some markets, clarifying transmission issues, and cleaning up balance sheets. Some companies are also busy managing fuel supplies and costs. In some states, utilities must plan to meet new renewable portfolio standards. In other states, non-emitting portfolios are mandated, allowing standards to be met by either nuclear or renewable energy.A period of relative stability, without the disruption of major new requirements for CO2 reductions, is a relief in an industry already struggling to manage costs and comply with environmental regulations. If gas prices continue rising at a moderate pace that can be explained as due to events beyond the industry's control (storm damage, terrorist acts, big demand growth from China), many utility leaders can avoid significant controversy and precipitous action, which could cause adverse reactions from consumers, regulators, and Wall Street. In many parts of the country utilities are also working to shore up transmission and distribution networks to deal with persistent reliability problems. Their regulators can argue persuasively that normal cost of service rules with incentives in various areas are working in the best interest of customers, and state and regional economic development. But, the pressure to keep rates low continues to dampen investment in infrastructure and new technologies.

Table 2-1
Key Provisions of the Energy Policy Act of 2005

Improves electricity transmission capacity and reliability. The legislation provides for enforceable mandatory reliability standards, incentives for transmission grid improvements, and reform of transmission siting rules.

Promotes a cleaner environment by encouraging new innovations and the use of alternative power sources by launching a state-of-the-art program to enable hydrogen fuel cell cars to compete in the marketplace by 2020. The legislation also authorizes $200 million for the "Clean Cities" program, which will provide grants to state and local governments to acquire alternative fueled vehicles.

Promotes clean coal technology and provides incentives for renewable energies such as biomass, wind, solar, and hydroelectricity.

Provides leadership in energy conservation by establishing new mandatory efficiency requirements for federal buildings, and efficiency standards and product labeling for battery chargers, commercial refrigerators, freezers, unit heaters, and other household products.

Clarifies the federal government's role in siting liquefied natural gas (LNG) facilities and provides an efficient approval process. Improved access to natural gas will help reduce high utility bills, create jobs, and provide further strength to the economy.

Decreases America's dangerous dependence on foreign oil by increasing domestic oil and gas exploration and development on non-park federal lands and by authorizing expansion of the Strategic Petroleum Reserve's (SPR) capacity to 1 billion barrels.

Encourages more nuclear and hydropower production by authorizing DOE to develop accelerated programs for the production and supply of electricity; setting the stage for building new nuclear reactors by reauthorizing Price Anderson; and improving current procedures for hydroelectric project licensing.

Source: http://energycommerce.house.gov/108/0205_Energy/05policy_act/ EPACT%202005%20Committee%20Print%20Highlights.pdf

Specific Implications for the Electricity Industry

1. Voluntary participant funding. Utilities and IPPs share cost of building new transmission lines; FERC may approve a participant funding plan if the plan results in rates that are just and reasonable, not unduly discriminatory or preferential.

2. No renewable portfolio standards. There are no mandatory requirements for utilities to provide electricity from renewable energy sources.

3. Mandatory reliability standards. Addresses the following: criteria for Electric Reliability Organization (ERO) establishment; enforcement procedures for ERO and FERC; ERO delegation of authority to regional entities; establishment of regional advisory boards; ERO reliability assessment and adequacy reports; ERO funding.

4. FERC backstop siting authority. DOE "in consultation with affected States" to complete study by 8/5/06 of electric transmission congestion and may designate "national interest electric transmission corridors".

5. FERC transmission pricing incentives. FERC is proposing to amend its regulations to establish incentive-based (including performance-based) rate treatments for the transmission of electric energy in interstate commerce by public utilities for the purpose of benefiting consumers by ensuring reliability and reducing the cost of delivered power by reducing transmission congestion.

6. Termination of PURPA mandatory purchase obligation. The requirement to purchase power from a qualifying cogeneration facility or qualifying small power production facility is terminated under certain competitive market conditions.

7. PUHCA repeal. The Public Utility Holding Company Act of 1935 is repealed six months from date of enactment; FERC is given increased merger-review authority.

Table 2-2
Poll Results on American Belief About Climate Change

"Do you think global warming is an urgent problem that requires immediate government action, or a longer-term problem that requires more study before government action is taken?"				
	Urgent Problem %	**Longer-Term Problem %**	**Not a Problem %**	**Unsure %**
9/23-27/05	41	47	6	6
6/05	38	58	3	1

ABC News/Washington Post Poll. Sept. 23-27, 2005, N=1,019 Adults nationwide. MoE+/- 3 (for all adults).
Fieldwork by ICR.

In this world, final energy consumers continue to focus on price and reliable delivery. Looking at technology development in the electric power sector, there is scant evidence of any major game-changing breakthroughs that can lower overall cost of energy delivery or offer fantastic new features. The evolutionary pace of development in fuel cells, gas turbines, efficient motors, real-time pricing systems, and the like are interesting, but mostly unexciting outside the realm of systems engineers and researchers.

U.S. energy policies are consistent with conditions in the global economy. Despite some genuine disappointment over the continuing U.S. position on climate change treaties, the U.S. continues to lead the world economy. *Real politik* dictates that sustained growth of U.S. annual GDP in the 3% to 4% range is essential for continued economic growth in Western Europe, China, India, and most developing nations. Global economic integration and trade are the drivers for relieving poverty and expanding wealth worldwide. Despite a large minority who worry and argue about climate change generated by human activity, the majority of world leaders in reality endorse a go slow approach. Even the Kyoto Accords, with many developing nations exempt from its requirements, can be considered only a small step in mitigating global change.

By 2012, seven years after the 2005 energy law, there are only moderate changes in the U.S. electricity sector. Due to the hurricanes of 2005, environmental and other site-related concerns have postponed building new liquefied natural gas (LNG) terminals in the Gulf of Mexico. Only the Northeast has new operating LNG terminals. Imports of natural gas from Canada via pipelines, however, have increased markedly. Thus natural gas prices have continued their steady rise and floated between $10 to $12/MMBtu, with occasional spikes to $15/MMBtu or higher. Nonetheless, some analysts argue that in real terms the prices are still not as high as in the mid-1970s and do not overly hinder economic growth, especially since the U.S. economy continues to become less energy intensive.

Table 2-3
Potential Development of LNG Sites

North American Regasification Projects: 16 out of 92 proposed new terminals have completed major project milestones (i.e., 10 are under construction)[1] and are likely to be completed by 2010, along with expansions at the four existing terminals. At a 70% capacity factor, this equates to 11.9 BCFD.
Liquefaction Facilities: 58 out of the 72 proposed new liquefaction projects worldwide likely will be completed by 2010 (i.e., 40.2 BCFD at a 100% capacity factor). Of these 12 with a capacity of 5.8 BCFD already are in operation.
Foreign Regasification Terminals: 54 out of 91 proposed new terminals likely will be completed by 2010 (i.e., 17.9 BCFD at a 70% capacity factor).
Supply Commitments: Based upon announcements to date, for approximately 70% of the likely liquefaction terminals supply commitments are as follows: 37 % for the North American market, 30% for the European market, and 33% for the Asian market.[2]
Spot Market: The current relatively small (i.e., 1.6 BCFD) short-term, or spot, market for LNG will increase to 8 to 10 BCFD by 2010.

[1] Counting each of the four Energy Bridge ships as a separate project.

[2] Undesignated supply are split between the three market areas.

Source**:** Natural Gas Price Forecasts and Planning Uncertainty, EPRI 1010251.

2013–2020

Some political watchers observe that the U.S. Congress can address energy issues and make new laws approximately once every decade or so. Pressure has to build from constituents and there must be a clear problem to address. At this time, political pressure comes mainly from an active and vocal minority who still clamor for an aggressive environmental stance on global climate change. Their scientific analyses and political arguments, however, are routinely countered by others who point to analytical uncertainties, weak evidence about the impact of man's activity on the global climate, and most importantly, undervaluing current rates of progress.

More importantly, political leaders who concede the "benefit of the doubt" on climate change science to the arguments that action must be taken, nevertheless point out that the problem cannot be solved without technology. However, there is little societal support for an aggressive R&D program, aimed at helping the transition to lower carbon emissions with cost-effective solutions. Meanwhile, most utilities have either met or exceeded requirements for adding renewables to their generation base. The U.S. maintains its steady 1% annual decrease in the energy intensity of its economy. Even the rate of growth in CO_2 emissions is declining on a national basis. Increases in natural gas and other fuel prices are gradual enough to have little real harm upon economic growth, though they provide incentive for increased energy efficiency.

At this time, the technology and scale of the global trade in LNG is firmly established and credible. Imports via pipeline from Canada and Mexico are insufficient for the long term, and the national interest in diversifying supplies leads to increased imports from Asia. The smooth operation of LNG terminals in the Northeastern U.S. raises the comfort level of the average American. That puts pressure on western Governors to allow terminals in their region. Despite protest over environmental and security concerns, construction begins on LNG terminals in the states of California and Washington.

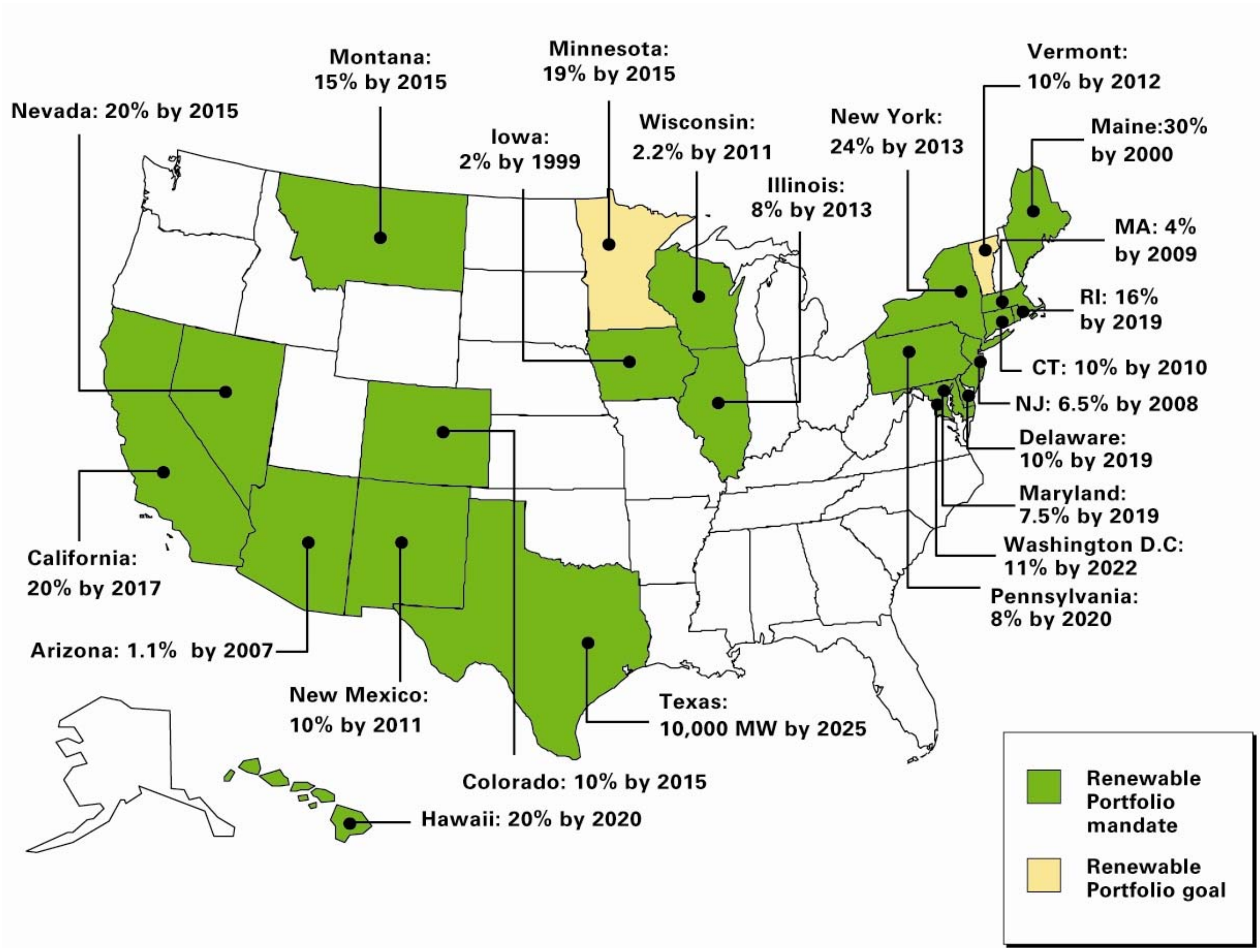


Figure 2-2
Renewable Portfolio Standards by State, as of 2005

Within the electric power industry, one notable development is the higher level of consolidation through mergers and acquisitions. In cleaning up the debris from deregulation efforts, some companies have acquired others, bought power plants, and made large-scale deals for expanding transmission systems. The larger scale allows companies to stabilize earnings and manage investment risks.

With regulatory oversight, many of the consolidations also have genuine benefits for utility customers. Electricity prices, though steadily increasing, are not rising at a rate that most businesses and consumers feel is unfair or damaging. In fact, provided it is reliable, power is in general not a concern for every day living.

2020–2025

In 2020, the best indicator of future energy development comes not from the U.S., but from legislation and regulatory change passed in China, which has come a long way in reducing poverty and increasing wealth. Now that the Chinese economy is about 75% as large as that of the U.S., its global warming emissions related to energy production are a hot international topic. China relies heavily on coal, hydro, and nuclear power. Its contribution to greenhouse gas emissions is just behind that of the U.S. Hence, China’s energy policy decisions are closely watched as a model for other developing nations. The Chinese Energy Law of 2020, not unlike the U.S. energy law of 2005, is an attempt to balance increased supply with incentives for energy efficiency and sustainability, designed not to compromise continued economic growth. It opens the door for more growth in LNG, secures the future of nuclear power, and gives growing support to renewable energy. It also addresses China’s transportation sector with incentives for efficiency and new technology investment.

Table 2-4
Growth Rate of Chinese Economy

Year	Growth Rate (% Per Year)
2000–2002	8%
2003	9%
2004	10%
2005 and beyond (best projection)	9–10%

The Chinese decision reflects the dominant worldwide consensus that despite fierce storms, droughts, and shifts in agricultural land use patterns, there is not a scientifically sufficient perception and politically persuasive evidence of extraordinary climate change due to human activity. Some observers point out that developing nations are following the U.S. pattern of the 1980s and 1990s in which increased wealth allows addressing environmental concerns, such as cleaning up lakes and rivers, improving air quality in urban zones, and using more efficient technologies. Many are importing power generation and other equipment from U.S. manufacturers. The U.S. now has one of the most diverse and balanced electric power bases in the world, with substantial renewables (especially wind), clean coal and natural gas, and nuclear generation.

The big news of the time is the approval and construction of a super storm-resistant LNG terminal in the U.S. Gulf region, based on a design that can withstand a hurricane with up to 250-mile-per-hour winds and huge water surges. Natural gas prices in the $12 to $14/MMBtu range, with spikes to $16/MMBtu, are sufficient to not only make the new terminal economic, but also support continued investments in energy efficiency.

If energy consumers and equipment suppliers have one small complaint, it is the lack of any "new" thing in energy that offers wonderful new features or capabilities. Plug-in hybrid cars are an interesting niche for some consumers, but are basically a mature technology. Most homes and businesses have abundant electricity at the flip of a switch, as has been the case for over 100 years. Of course, warnings persist that the world is running out of oil and that every summer heat wave indicates global warming. Such ideas simply do not carry the day with the average voter in the U.S. and in most of the world.

Areas of Technology Development

The world of Digging in our Heels is characterized by the continuation of current trends related to high fuel prices and manageable costs to meet environmental requirements in the energy sector. The focus is on short-term operations issues—fixing problems—rather than creation of fundamentally new technologies. Executives and managers recognize that strategic issues will have to be addressed, but they postpone the needed work. Instead, they are forced to spend time on urgent crises that divert their attention from longer-term issues. Nevertheless, progress is evident in some areas. In the consumer sector, end-use efficiency improvements are effective in lowering costs and reducing the need for adding generation capacity. The consumer portal links information technology with the grid, leading to a requirement for ubiquitous computing. The IT revolution leads the way to a more reliable power delivery system. Important developments are evident in the supply side as well, as generating companies strive for a balanced portfolio of generation options. Some of the most important issues include the relative value of distributed versus central station generation and the role of non-emitting (renewable and nuclear) generation. Research is also needed to understand the role of coal—do we extend the life of the current fleet of coal-fired plants or develop new technology, such as integrated gasification combined cycle (IGCC)? What are the relative costs of these options? One suggestion is to retire subcritical coal plants and upgrade with either IGCC or NGCC technology.

Table 2-5
Areas of Technology Development—Digging in Our Heels

Technology Themes	Technology Gaps		
Sustain Nuclear Fleet	Advanced high burnup fuel	Resolve plant security issues	Technologies to support life extension
Advanced Coal	Commercial availability of IGCC	Develop and demonstrate advanced PC	Regulatory framework for CO_2 sequestration
Sustain Gas Generation	Reliability of supply	Maintain efficiency across load range	Cycling capability
Carbon Capture and Sequestration	Improve efficiency for IGCC and PC	Novel technologies for carbon capture	Reliability of long-term storage
Environmental Emissions	Clean Air Act compliance (SO_2, NO_x, Hg, particulates)	Advanced scrubbing for CO_2	Availability and adequacy of water supply
Renewable Resources	Methodology for wind siting	Wind variability and system regulation	Biomass cost and efficiency
Distributed Generation	Integrate distributed generation with grid	Address siting considerations	Integrate with storage
Energy Storage	Increase storage round-trip efficiency	Integrate storage with distributed energy resources (DER)	Cost reduction of all storage technologies
Transmission Portfolio	Need for dynamic real-time security systems	Low-cost FACTS	High cost of underground transmission
End-Use Efficiency Improvement	Smart controls for appliances	Integration of appliances with Internet	Consumer education
Customer Portal	Protocols, standards for RTP	High cost of automated metering infrastructure	Need for ubiquitous computing
Distribution Automation	Integration of distributed controls	Improve communications infrastructure	Storage to reduce need for supply additions
Building-Integrated Energy Systems	DC bus for IT equipment	Sensor and data integrity	Recycling of industrial waste energy
Plug Hybrid Electric Vehicle	Need to improve battery cost	Greater number of charging cycles	Smaller battery weight and volume

3
SUPPLY TO THE RESCUE

Supply to the Rescue is a world that relies on supply-side solutions to a broad range of energy issues. The abundant supply of low-cost natural gas in this world spurs economic growth and development, particularly in energy dependent businesses.

In this world, government and industry make large investments that lead to ample supplies and stable moderate prices for both natural gas and other primary fuels. Consumers and politicians believe that the current pace of moderate improvements in environmental quality is sufficient to meet societal goals and that technological innovation will continue to provide improvements on a timely basis. They prefer continued and stable economic growth over a difficult-to-prove connection between energy use and climate change.

North America (U.S., Canada, and Mexico), Western Europe, China, and India anchor global economic growth as world trade expands and international conflicts diminish. Technological innovation in computing, communications, bio-science, nano-technology, and other areas continues to move the U.S. toward a more knowledge-based economy with decreasing energy intensity. The shifts in global production and distribution of goods continue to impact the nature and level of job growth in the U.S., but overall economic growth continues at a moderate pace.

Some natural gas reserves are located far from the likely point of end use in the U.S. and thus influence U.S. geopolitical and military planning. To address national security concerns, the U.S. moves ahead quickly with infrastructure development to enable the importation of more natural gas. This trend continues as more new gas and oil discoveries are brought on line. Developing and implementing LNG technology moves to a level of international cooperation that mirrors that in oil development and transportation.

Eventually gas prices fall relative to coal and gas is the most competitive choice for power generation. With low gas prices, many utilities and companies install relatively inexpensive distributed generation systems with easy access to existing and new gas supplies. Energy suppliers point out that displacing coal generation with natural gas for power generation reduces CO_2 emissions—a “no regrets” strategy.

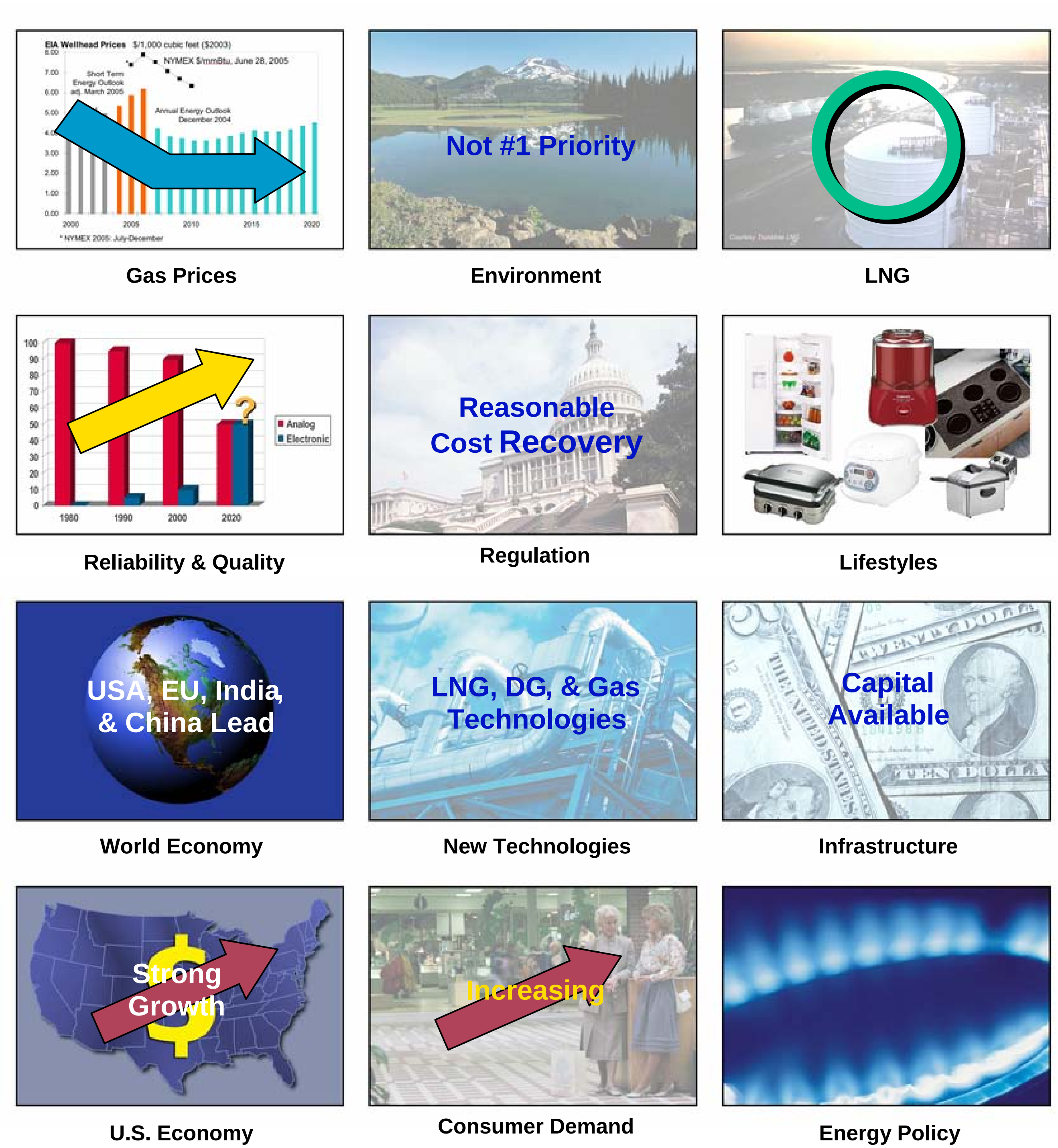


Figure 3-1
Overview of Supply to the Rescue

Full Scenario Narrative

2005–2012

Abundant oil and gas supplies and an unclear link between human activity and climate change guide the next two decades. In terms of fossil-fuel potential, large parts of the world are unexplored and barely exploited. Plenty of supply has yet to be tapped and high prices attract the capital needed to bring on more supply. The high prices in late 2005 are just part of a natural cycle with a few short-term extraordinary events, such as storms and terrorist attacks. Oil and natural gas have long-term futures of at least three decades. Alternative sources of oil, such as tar sands and oil shale, also have supplies that could last for decades. In addition, coal supplies that could last for hundreds of years are available.

Climate-change analysts know that current models are unable to specify which factors are affecting the world's climate. The earth and the sun go through cycles with much larger effects that what mankind's activities could cause. Even if analysts are wrong, they believe that, during the next 20-year period, it is possible to design new technology to substantially reduce greenhouse gas emissions through efficiency, as well as to capture and economically, safely store CO2. And, the existing investment in fossil-based technologies makes the economics of efficiency and capture-and-sequestration of CO2 much more competitive than many alternative energy advocates are willing to admit. Similarly, the economics of nuclear generation make it competitive with other generation technologies.

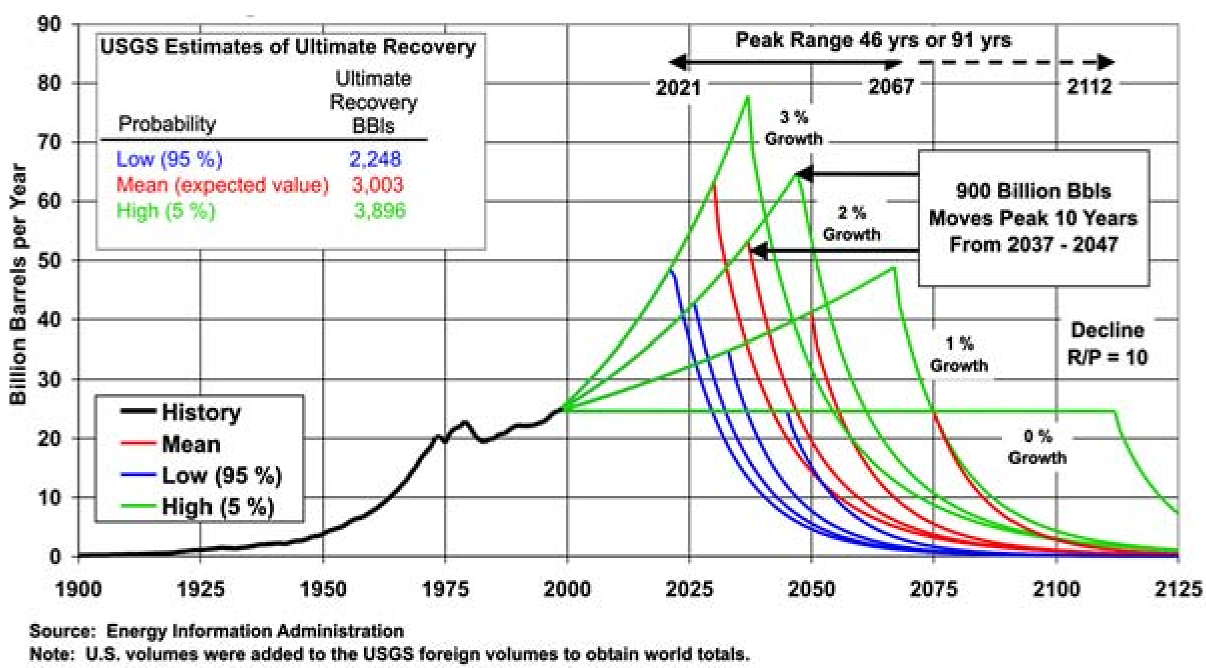
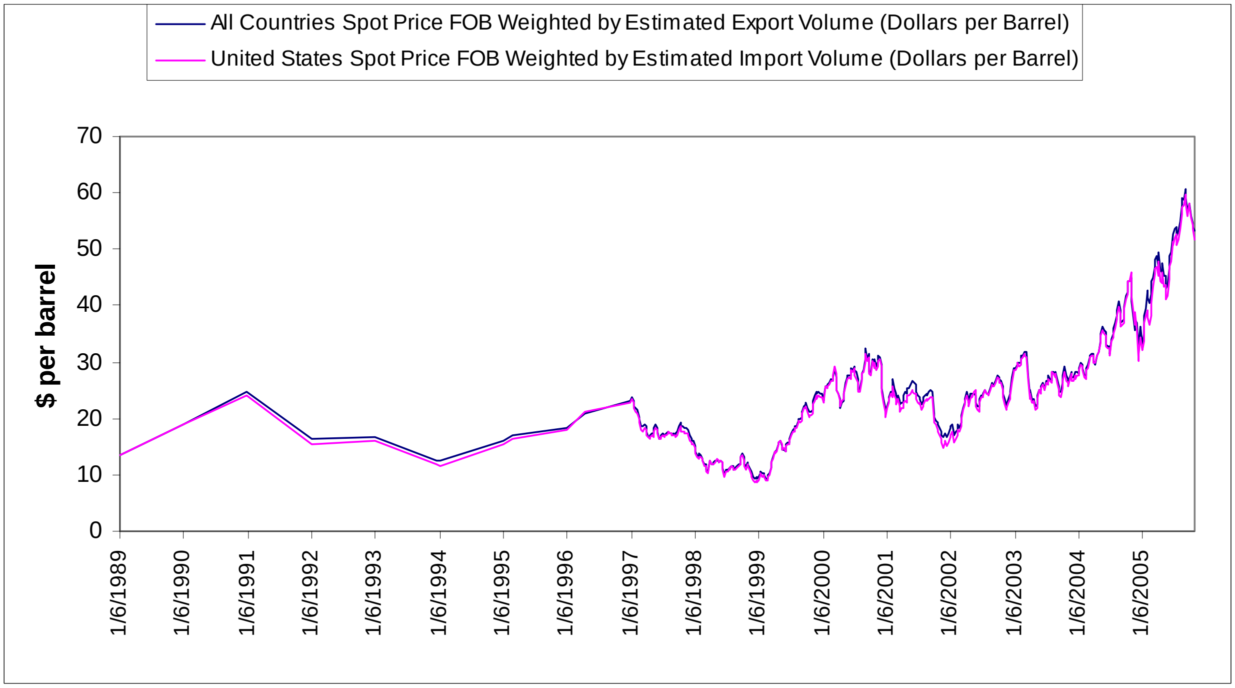


Figure 3-2
Projections of Long-Term Oil Production



Source: U.S. Department of Energy, Energy Information Administration, Updated on 11/2/05.

Figure 3-3
Historical Oil Prices

In 2005, U.S. political leaders believe in stepping up to the need for more exploration and development, the building of LNG terminals, and letting energy prices rise without interference so that market signals can attract the needed capital to the industry. They argue this simply has to be done despite criticism from some quarters.

Taking a strong position on climate change takes political courage and stamina. Stating that severe storms, despite serious damage, are not proof of global warming is not universally popular. But political leaders focus on the American economy's need for energy so that the U.S. can keep growing and playing its role in building global wealth. Ground work was laid in the 2005 Energy Policy Act, and other actions that bolster America's energy security follow.

Within the U.S. electric power industry in 2005, conditions are just stabilizing from the disruptions caused by mixed results of industry restructuring and "de-regulation." The power industry is working through law suits, addressing excess generation in some markets, clarifying transmission issues, and cleaning up balance sheets. In some areas, they get comfortable with cost-of-service regulation and performance-based regulation. U.S. political leaders provide support, which makes it easier to supply the energy and technology America needs for its future. In particular, government actions to ease financial risks of large investments, fund long-term research and development, and clarify regulations are particularly helpful. The industry thinks it can handle rising energy prices best by increasing supplies *in combination* with other proven technologies to increase energy efficiency and balance fuel supply portfolios.

The approval of LNG terminals to serve the Eastern U.S. in 2006 and 2007 establishes U.S. energy companies as full participants in a growing industry that has a track record in other parts of the world dating back to the early 1980s.

U.S. energy ties with Canada strengthen as Canada brings on line the gas reserves of the Mackenzie Delta and expands production of the Alberta oil sands. Ultimately, North America becomes the most powerful and influential energy region of the globe.

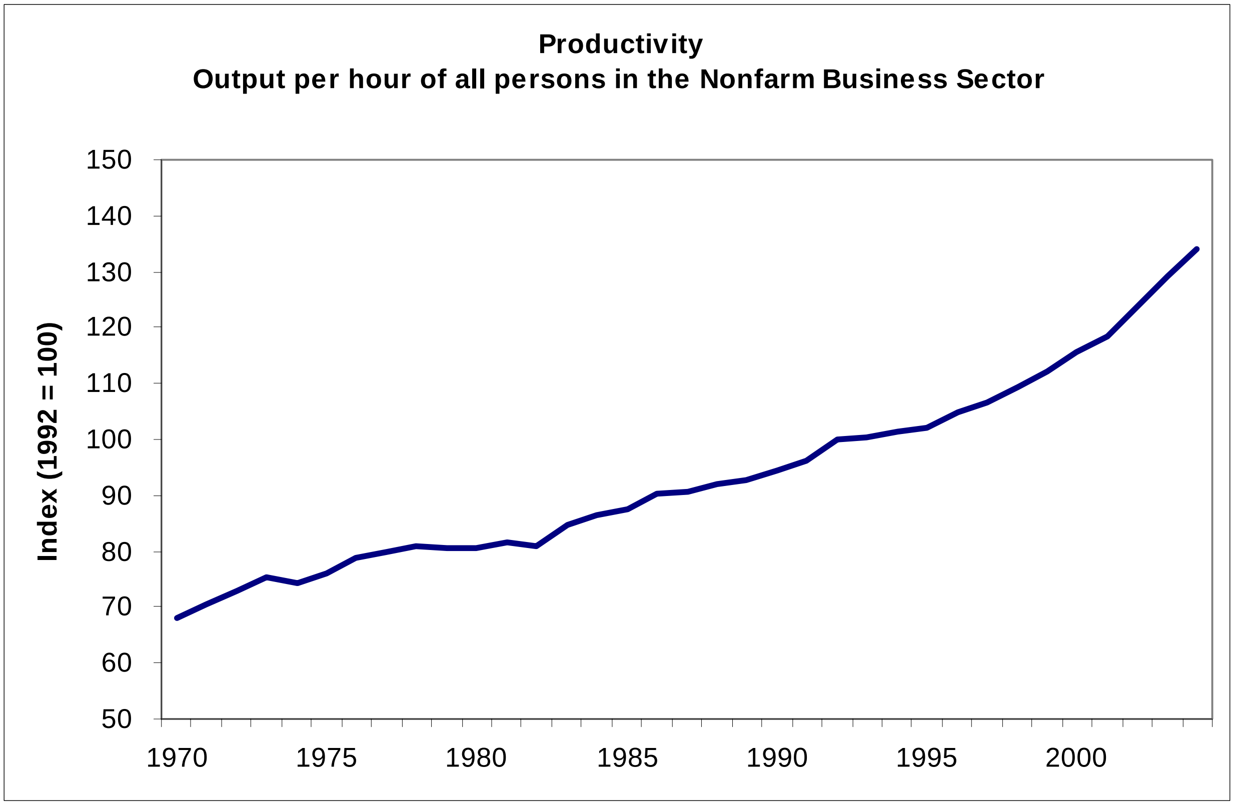
In this world, national security concerns are easily addressable and do not become a major issue. Gas prices in the $9 to $11/MMBtu range are sufficient to encourage additional investment in new gas supplies. Market forces are allowed to work to bring demand and supply back into balance, thus reducing pressure on prices. Although there is some concern about doing extreme and irreparable damage to the environment, most Americans agree with the notion that some environmental change is acceptable and necessary to accommodate “normal” living.

2012–2019

Reducing the incidence of terrorism around the world provides big benefits in terms of world oil and gas prices. Not only are “terrorism premiums” removed from market prices, but market expectation of additional supply depresses speculation. As a result, the Middle East, Southeast Asia, South America, and Asia develop additional oil and gas supplies, which in turn leads to a diversity of sources that enable better risk management.

As natural gas prices fall in the U.S. and new generations of efficient turbines and fuel cells move into production, the electric power industry feels safer in increasing its reliance on natural gas while offering power that is competitively priced. Regulated utilities are assured of cost recovery in all cases, so they build more wind turbines and nuclear power plants to meet renewable and non-emitting generation portfolio standards. The real challenge for some is their long-term investment in coal-fired facilities; many find it wise to retire these plants at the end of their economic lives and move to natural gas.

By 2012, U.S. consumers are using less energy. Lower energy use, together with productivity gains, makes energy costs a smaller part of their cost of living. This results in increasing real wages for middle and upper-class Americans and produces a wealth effect. (This trend appeared several times before with advances in technology or the maturing of market supply. As energy reliability and security improved, the energy industry was no longer in any state of “crisis.” Any problems were generally of a short-term nature or they reflected a need for more infrastructure.) Periodic power outages in many American cities still send Americans into fits of anger, but outages are irregular and have minor consequences for all but the largest consumers, so most people forget them as soon as power is restored. Business and industry that could be hurt by such outages have back-up power solutions.



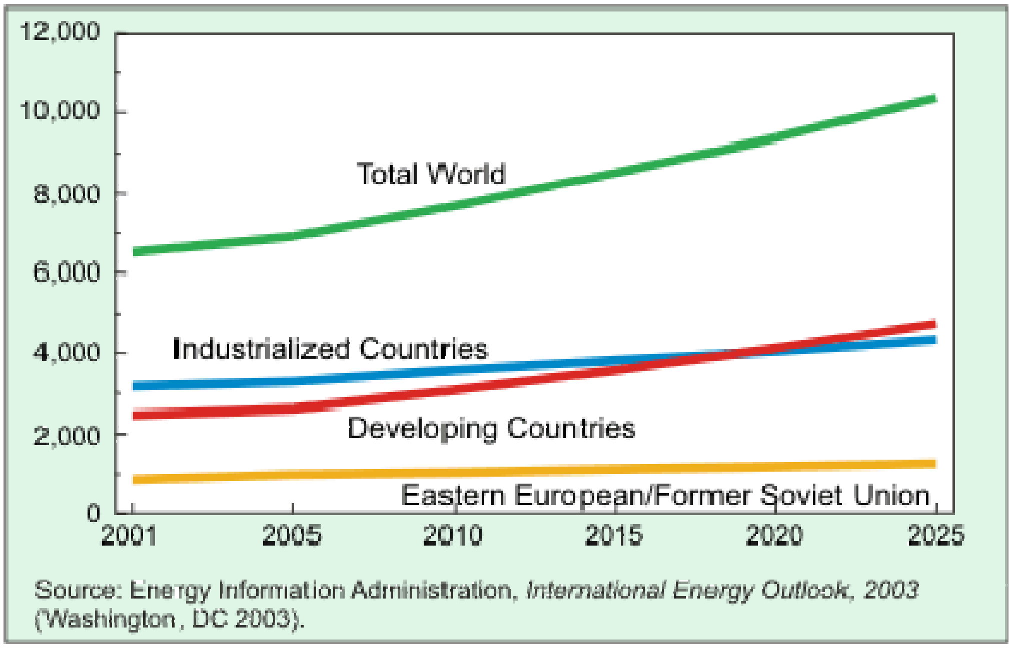
Source: Economic Report of the President, 2005.

Figure 3-4
Productivity Growth in the U.S.

Fast on the heels of the new Gulf Coast terminals, the West Coast in 2014 completes its first LNG terminal, which anchors America's future in natural gas supplies. The online terminals immediately trigger a fall in natural gas prices, back to $8/MMBtu, but eventually prices stabilize at just under $10/MMBtu as some older coal plants are retired in the Southeastern U.S.

In 2016, after a series of fierce storms do extensive damage to the Southern U.S., renewed calls arise for regulation of fossil fuels. But an analysis of the U.S. power sector shows progress in lowering greenhouse emissions per unit of economic activity, even if total emissions are rising due to economic growth. These results convince political leaders that the industry is on the right track. Energy executives also point out that growth in emissions from developing countries is far outpacing U.S. emissions growth. U.S. energy companies are already implementing the best-known technologies in the world and penalizing them would not help. Also many economists point out that the developing countries will be in a better position to control such emissions when they became wealthier and are able to invest in improved infrastructure and better technology. They argue that time is on our side and the best environmental policy is the elimination of world poverty.

World Carbon Dioxide Emissions by Region, 2001-2025
(Million Metric Tons of Carbon Equivalent)



Caption: World carbon dioxide emissions are expected to increase by 1.9 % annually between 2001 and 2025. Much of the increase in these emissions is expected to occur in the developing world where emerging economies, such as China and India, fuel economic development with fossil energy. Developing countries' emissions are expected to grow above the world average at 2.7% annually between 2001 and 2025; and surpass emissions of industrialized countries near 2018.

Source: http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html

Figure 3-5
CO_2 Emissions

2020–2025

Experienced industry leaders did not expect long-term high commodity prices—and they are right again. Commodities, they argue can sometimes have upward cycles, but short of real structural change, high prices don't last. And even if prices move to a new plateau due to a structural change, competition will likely exert downward pressure. This is exactly what played out following the building of a network of LNG terminals servicing the U.S. market. Natural gas prices fall back into the $8/MMBtu range. Coal prices, struggling for years to compete with abundant natural gas, all but collapse.

Integration of the global economy, especially around energy supplies, is so complete that events any where in the world can change prices and supplies throughout the world. However, quick responses, such as the rapid redirection of supplies, keep prices within a fairly narrow range. For the U.S., the biggest market in the world, energy prices are generally stable. Overall economic growth in the U.S. remains stable as well. On a fundamental basis, the U.S. has all the supplies of energy and resources it needs.

In sum, this world is bigger, more global, and more integrated. In many ways it is more efficient and cleaner. The challenge of really arresting and lowering greenhouse gas emissions remains, but it is unclear how necessary this really is.

Areas of Technology Development

The world of Supply to the Rescue is characterized by an expansion in primary energy supply that moderates prices and a continuation of low and manageable costs to meet energy sector environmental requirements. The technical thrust of the Supply to the Rescue world is gas—global exploration and production, transport and handling, and the role of LNG. Gas development on the scale needed will require global cooperation among all stakeholders. This cooperation will mirror the experience (and exemplify the risk) of the global oil industry. Cost and technology developments in power infrastructure will influence the course of distributed generation. A distributed generation future will require technology development to assure safe, reliable, cost-effective, and user-friendly operation of the generation system. User education will become an important theme of technology development. Grid reliability issues are also important in this world, due in part to the need to understand the processes of integrating distributed generation with the grid. Ultimately, nuclear energy expands significantly, and IGCC may gain traction in this world as a means of keeping gas prices low. The focus of technology development here may emphasize methanation, the production of pipeline quality gas from coal.

Table 3-1
Areas of Technology Development—Supply to the Rescue

Technology Themes	Technology Gaps		
Sustain Nuclear Fleet	Economic life extension	Life limiting materials issues	Sustained focus on security and protection
Advanced Coal	IGCC as backup to gas	Further emphasis on conversion efficiency	Replace subcritical coal units with natural gas
Sustain Gas Generation	High efficiency gas plants—Frame H and beyond	Gas as transition fuel to lower CO_2 world	Sequestration of CO_2 from gas generation
Carbon Capture and Sequestration	Improve efficiency for IGCC and PC	Develop IGCC as a backup for gas	Commercial deployment of IGCC
Environmental Emissions	Focus on reducing emissions from gas generation	Advanced scrubbing for CO_2	Availability and adequacy of water supply
Renewable Resources	Limited role for renewables given focus on gas generation	Gas/biomass integration	Biomass cost and efficiency
Distributed Generation	Integrate DG with controls systems	Site DG in locations where it reduces T&D congestion	Improve efficiency of combined heat and power installations
Energy Storage	Pilot plant studies and full-scale demos of storage applications	Integrate gas and electricity storage with DER strategy	Continued reduction in cost of all storage technologies
Distributed Generation	Integrate DG with controls systems	Site DG in locations where it reduces T&D congestion	Improve efficiency of combined heat and power installations
Transmission Portfolio	Address larger current flows due to lower electricity prices	Software for real-time T&D costing	Improvements needed for voltage stability and thermal limits
End-Use Efficiency Improvement	Electrotechnologies for process, manufacturing, and service industries	Corn drying and other agriculture applications	Recycling of industrial waste energy
Customer Portal	Establish linkage with T&D reliability	Uncertainties regarding outside participation	Wireless advances
Distribution Automation	Large gas supply increases DG	Load shedding to ensure system stability	Storage to reduce need for supply additions
Building-Integrated Energy Systems	CHP and DC in the home	Photovoltaic roofing tiles and windows	"Zero energy" buildings
Plug Hybrid Electric Vehicle	Need strategy for speeding adoption, especially if fuel prices are low	Continued battery performance improvement	

4
DOUBLE WHAMMY

Double Whammy, as the name suggests, incorporates both high gas prices and high societal concerns about environmental costs. Taken together, these factors produce a more than proportionate share in their impact on the economy. Technology advances offer a collaborative basis for meeting the challenges of this world.

Double Whammy reflects a significant change in beliefs and values of the majority of Americans, industry, and government leaders toward the position that anthropogenic changes in global climate are occurring, that they are harmful, and that they must be addressed soon. There continue to be conflicting scientific opinions regarding man's activities and global climate change, but the political perceptions about harm make the debate moot.

The U.S. joins an international consensus that is willing to accept sudden shifts and sustained high prices for traditional energy sources. The expectation is that the resulting technology upheaval and shift in investments by government and businesses will eventually moderate energy demand and costs while sustaining the environment. As a result, businesses and consumers face increasing fuel prices due to policy or taxation and lingering demand, and these higher prices do not fall off immediately. The direct and imputed cost of CO_2 emissions grows rapidly at first, but over time increases more slowly.

This policy shift sets off a boom in investment and innovation. Business leaders see not only market potential, but are also anxious to invest in short-term and long-term technology innovations that can support global competitiveness.

Led by North America and Western Europe, a mutually supportive atmosphere evolves between business leaders, politicians, and consumers to combine voluntary actions and market incentives to shift energy use patterns toward a cleaner and more sustainable path. The initial focus is on conservation, improved end-use efficiencies, combined heating and power, renewables, and other "soft path" technologies. Over time, innovations occur that generate surprising impacts on efficiency, cost, and environmental quality while delivering enhanced features.

In many cases, China and India find it easy to install the best available environmental technology because they have no sunk base of assets. Instead, their economic growth keeps fuel demand up.

Interestingly, clean, coal-based generation becomes an important element in a transition strategy to replace fossil generation with non-CO_2-emitting generation. Gas is at a disadvantage because of its high cost, and the high cost of capturing CO_2 from the flue gas of a gas-fired generator. Over time, policy makers realize that renewables are incapable of addressing climate change on their own, so they commit to nuclear power and advanced clean coal as a major part of their generation portfolios.

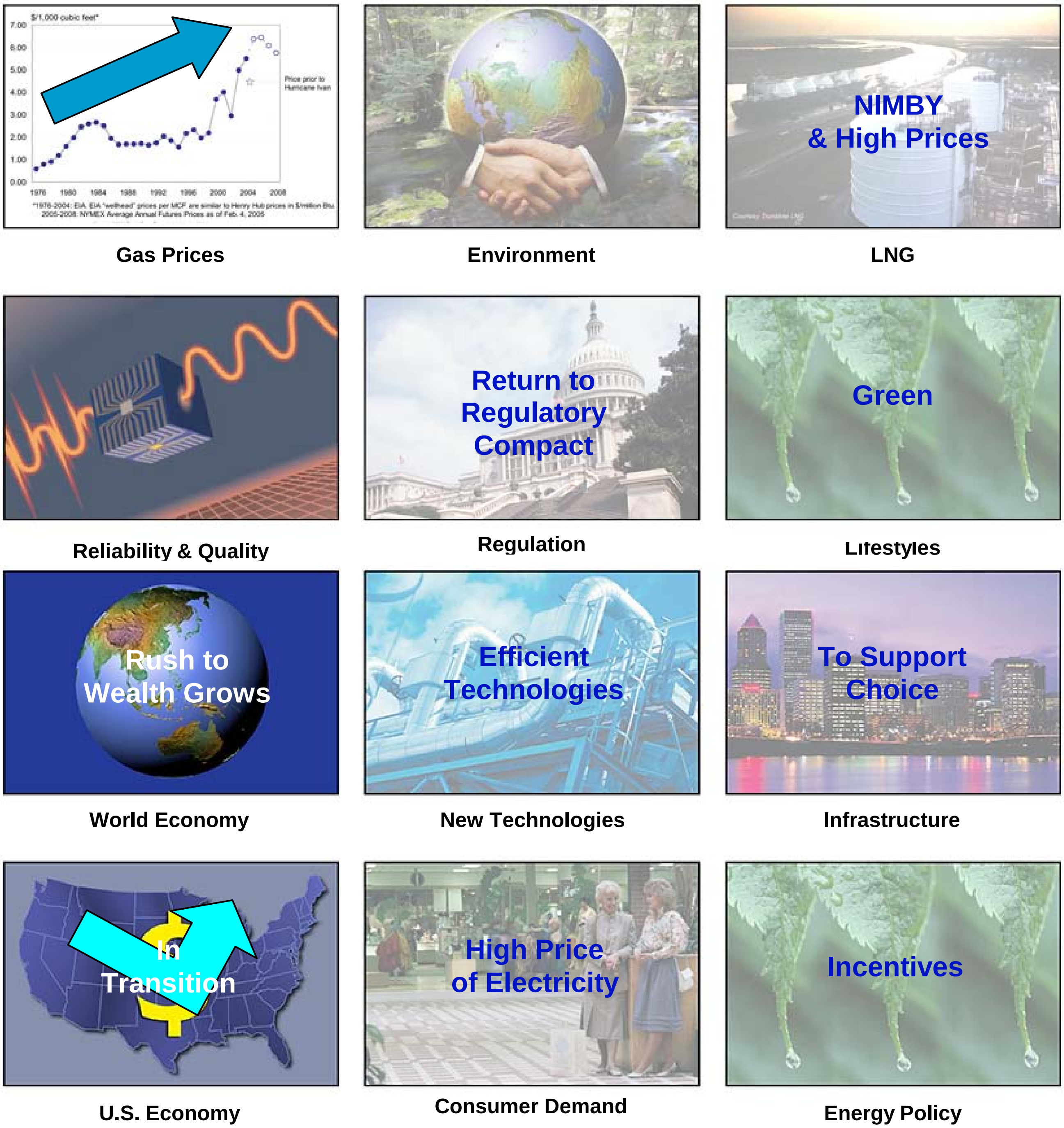


Figure 4-1
Overview of Double Whammy

Full Scenario Narrative

2005–2012

In this world, Greenpeace and General Electric both succeed. The long-standing environmental movement succeeds in making U.S. citizens and people worldwide more concerned about the impact of mankind's economic activities on the environment and earth's climate. Innovative companies succeed in pursuing technologies that achieve big results (and big profits) in addition to a cleaner environment.

Building on the success of the environmental movement that cleaned up rivers and lakes and improved air quality in major U.S. cities, groups dedicated to promoting more environmentally sustainable lifestyles see political and social movement in their direction and achieve a pivotal change in U.S. policy toward rules that address greenhouse gas emissions. As this political transition evolves over the next two decades, prices for primary fuels rise steadily, first due to continued growth in demand driven by global economic expansion, and secondarily by increasing taxes and other penalties for fuel use. Increasing prices play right into the hands of innovators, making their alternatives more competitive.

Table 4-1
Potential Key Renewable Technologies

Technology	2003 (Billion kWh)	2025 (Billion kWh)
Hydroelectric	275	307
Biomass	37	81
Geothermal	18	33
Wind	11	35
Municipal Solid Waste	22	29
Solar Photovoltaic and Solar Thermal	1	6
Total	**364**	**491**

Notes: Data from U.S. DOE Annual Energy Outlook, February, 2005.
Biomass includes combined heat and power and cofiring with coal.
Municipal solid waste includes landfill gas.

Within the U.S. electric power industry in 2005, conditions are just stabilizing from the disruptions caused by mixed results of industry restructuring and "de-regulation." The power industry is working through law suits, addressing excess generation in some markets, clarifying transmission issues, and cleaning up balance sheets. Some companies are also busy managing fuel supplies and costs. However, within labs, and even some proverbial garages, a growing contingent of engineers, entrepreneurs, and hobbyists are investigating means to make the energy industry more efficient, cleaner, and more pleasurable for consumers. Many see opportunities to expand the use of advanced nuclear generation, renewable energy technology, distributed generation, solar power, and advanced storage systems. Engineers and energy economists also suggest that many of these technologies would find wider use in the market if traditional energy technologies were paying their full cost, especially related to environmental externalities. However, the majority of energy industry leaders are concerned about imposing such costs because it would challenge their sunk investments. Nevertheless, a growing niche of business leaders in some of the biggest companies are beginning to see new possibilities and opportunities for profit in creating new energy systems and models of service.

In the broader economy, the big story is global economic growth and the emergence of China and other developing nations. Demand for all major commodities, but especially fuels, is increasing prices. Natural gas demand in the U.S., spurred by expanded use in the power sector and economic growth, is pushing natural gas prices into the $10 to $12/MMBtu range with no slow down in sight. Global trade, immigration, and low interest rates keep U.S. GDP growth around 4% and allow the U.S. to anchor world economic expansion. To maintain growth, the U.S. approves siting new LNG terminals on the Eastern Seaboard in 2006.

The 2008 national elections prove pivotal in shifting U.S. environmental policies to a new level. Following several years of destructive storms in the Southern states and melting ice caps, environmental concerns rise to the top of the political agenda. The winning Presidential candidate poses a challenge to voters, "Let's work together to create a cleaner future!" He promises to bring both scientific and business leaders to the table to develop a policy that demonstrates U.S. concern, a policy of which Americans can be proud.

By mid-2009, the President follows through on his promise and signs America's first comprehensive climate change law. It immediately sets a price on CO_2 emissions at twice the imputed rate that governed the industry. The law contains a schedule of slowly-escalating prices and penalties. It also contains incentives and government R&D investment to support industry innovation and consumer action. The new law's provisions are phased in so that businesses have some time to adjust, but it also has real teeth in penalties to spur change and actively manage the transition away from fossil fuels. Government is firm in its support role of encouraging industry to lead with innovation and investment in shifting the U.S. economy to its next-generation energy supply base. The majority, and clearly the more centrist environmental organizations, supports the government's actions.

The world reacts to the U.S. move as if it were a lightning strike. Other countries, including much of the developing world, which were dragging their feet in terms of addressing climate concerns, begin to review and change their laws as well. These changes build momentum and send an important signal to the global investment community—it is time to move!

2013–2019

The "new word" on newscasts is turnover rates, an arcane term not familiar to the average American. But, as with outsourcing and ozone holes, citizens are now becoming familiar with the slow turnover of infrastructure, real property, and equipment because it explains why things are not changing as fast as some want and expect. Fossil fuel use is still high and prices are rising. The transition is happening, but at a moderate pace. As the second decade of the century unfolds, a much-needed investment boom gains momentum.

Table 4-2
Turnover Rates

	Average Service Life (Years)
Automobiles	10–16
Single-family homes	75–100
Central air conditioners	10–17
Furnaces (gas-fired)	12–20
Refrigerators	10–16

Sources:
Appliance Magazine, A Portrait of the U.S. Appliance Industry, Sep. 2004.
ASHRAE, 1999 ASHRAE Handbook: HVAC Applications.

Consumers need time to learn about new technology options and adjust to their particular features. Further, nuclear energy production costs are significantly lower than both coal and gas. Just as cell phones went from “bricks” to photo-taking flip phones over a 20-year period, new solar designs, emerging fuel cells, and battery systems offer new features related to cleanliness, mobility, reliability, security, and power quality. Similarly, engineers accustomed to running coal plants have to learn how to match wind energy systems with hydro-based firming and energy storage services and to run chemical plants that produce gas from coal and capture CO_2.

As a result, natural gas is more costly than coal as a transition fuel for the electric power industry. This causes strategies to shift substantially. For some companies which had planned on natural gas as a long-term fuel solution, it is a 180-degree turn. By 2015, several new large nuclear plants are on line, and integrated gasification combined cycle (IGCC) is a commercially available option capable of economically capturing 95% of the CO_2 it produces. This technology keeps coal in the game as a possible low-emission transition fuel.

But what is most evident is the positive reception that many companies receive from state legislators for their attention to energy efficiency, which is no longer considered a niche play. Many utilities are also finding positive reactions from state regulators for incentives to help customers invest in higher levels of energy efficiency while allowing regulated utilities to continue to earn a return. Equipment suppliers to the industry pursue research and development and venture capitalists fund related investments as increasing energy prices make new approaches economic.

During this period of transition, the U.S. encounters some economic bumps in the road. A slowdown in constructing LNG terminals in the U.S. forces slower growth in natural gas consumption as no additional terminals are planned by industry. Even though gas prices are topping $15/MMBtu during the winter months, long-term forecasts are for stable to declining demand growth. Much of the decline in natural gas consumption will come as efficient machinery displaces old equipment. Many power companies are rethinking their infrastructure investments and focusing on improving transmission and distribution systems to facilitate energy trading and more options close to the point of consumption.

Despite changes in the energy industry, continued global economic growth dampens the visible and immediate impact on greenhouse gas emissions. There is a marked slow down in the rate of greenhouse gas growth, but no actual reduction on a global basis. Growth in the developing world is overwhelming the efficiency gains and declining use in mature economies.

Environmental activists and some political leaders argue that not enough is being accomplished and more stringent requirements are needed. They also suggest that more incentives are needed to encourage a faster uptake by consumers for some products, especially when they are stubbornly holding on to old equipment.

2020–2025

It took about fifteen years for changes to bear real fruit. During that time, there are many demonstrations of human genius and ingenuity, plus healthy doses of good old-fashioned greed. By 2020, long-term investments and risk taking by companies with foresight are beginning to pay off in growing earnings.

2020 is also the year for sustained and faster uptake of technologies that move the power sector away from fossil fuels as a primary part of its base. By this time, utility executives are boldly forecasting the end of the era of natural gas, just as they had dropped oil in the 1980s and 1990s. Modern power companies have made the conversion to energy services companies in a big way. They offer a range of energy supply and management options to meet individual customer's needs, including reliability and quality. Many parts of their businesses use off-the-shelf equipment and are no longer regulated in the traditional cost-of-service manner by statewide agencies. There are new companies in the competitive market, and some are dominating in energy services markets.

A notable development grabbing some headlines is the first decline of the three-year rolling average growth rate of CO_2 emissions on a global basis. Scientists predict that the trend will continue downward as more developing countries convert to modern clean technology.

Importantly, the progress in emission reduction happens while there is moderate growth in the world economy, so it is not a trick of an economic recession. Although there have been short recessions over the last decade, none are due to factors related to energy market adjustments. The transition to a more modern energy base is being accomplished without much sacrifice in economic growth.

Progress is evident across all energy consuming sectors from transportation to electric power use. That so much progress was made far ahead of any projections early in the century is a tribute to technological wizardry and changed lifestyles. The biggest change is the improvement in energy efficiency and the rapid adoption of much smarter equipment across the board.

On a global basis, there is agreement on the need for stringent emissions targets. However, the targets are neutral with respect to the generation mix, and the combination of generation and end-use technologies companies can use to achieve the target. This allows the U.S., China, and India to augment nuclear generation with their large indigenous coal reserves (using clean IGCC technology as described above). Fossil fuel prices are high mostly by law, not so much as a result of demand growth. Taxes and penalties effectively compose over 50% of natural gas prices in the U.S. LNG imports into the U.S. begin declining as old natural gas turbine units are being retired.

Though still the world's largest economy, the U.S. shares global influence with Europe and Asia. Trade relations and global economic integration make the best available technologies widely available. Thus, the latest energy innovations may be demonstrated or implemented in China and India, just as easily as the U.S. or Europe.

This is a world where Green activists who were in the movement two decades prior would admit that things are not only much better, but they are likely to get better still. Some would even admit that big companies had made the difference.

Areas of Technology Development

The world of Double Whammy is characterized by high prices for primary energy supplies and high and rising costs to meet energy sector environmental requirements. The high gas and CO_2 cost creates an atmosphere that favors technology development aimed at reducing costs as well as improving the environment. There are both demand side and supply side dimensions to the technology development requirements, met by market forces that support innovation and new product development. Large central station generation will enter a period of transition to meet more stringent environmental requirements, thus efficiency and low-cost mitigation will be important. Market responses lead to collaboration and sustained investment in research and development of new and alternative energy products and services to meet more stringent environmental requirements. This world has a great role for nuclear energy and renewable sources and energy efficiency. Distributed generation might play a key role in a system integrated with renewables.

Table 4-3
Areas of Technology Development—Double Whammy

Technology Themes	Technology Gaps		
Sustain Nuclear Fleet	Second wave of license renewal	New construction at existing sites by 2010	Advanced reactors provide process heat
Advanced Coal	Further increase in IGCC efficiency is critical to this scenario	Methanation (pipeline quality gas from coal)	Gasify coal and transport to thermal site
Sustain Gas Generation	"Zero-emission" gas plant	Solid oxide fuel cells—60% efficiency	Methane hydrate development
Carbon Capture and Sequestration	Technologies for carbon capture, transport, and storage	CO_2 capture from coal combustion technology	EOR for CO_2 injection
Environmental Emissions	Advanced scrubbing for CO_2s	Environmental dispatch	Management of multiple species of emission
Renewable Resources	Limited role for renewables given focus on gas generation	Gas/biomass integration	Biomass cost and efficiency
Distributed Generation	Assess impacts of vehicles and industrial customers on loads	Micro-DG for white goods and residential computers	Assess whether prices will drive consumers to self-generate
Energy Storage	Pilot plant studies and full-scale demos of storage applications	Integrate gas and electricity storage with DER strategy	Continued reduction in cost of all storage technologies
Transmission Portfolio	New renewables require reconfigured transmission system	DG reduces need for transmission	Superconducting cables for transmission and distribution
End-Use Efficiency Improvement	Micro fuel cells for home use	Advanced motors, pumps, refrigeration	Expansion of LED lighting
Customer Portal	Demand response pricing and load control	PQ data acquisition available at portal	Integrate building EMS with energy services supplier
Distribution Automation	Transformer replacement to reduce reliability consequences	Integration of large groups of distribution load controllers	Predictive tools to facilitate distribution management
Building-Integrated Energy Systems	Integrated systems for planned communities	Broad commitment to energy beneficial building materials	"Zero energy" buildings
Plug Hybrid Electric Vehicle	Use of alternate fuels in transportation sector	Confirm large net CO_2 reduction benefit	Reduce complexity of integrating auto and power sectors

5
BITING THE BULLET

Biting the Bullet refers to the need to take painful actions in the near term to forestall even more painful consequences in the future. The climate change issues of Biting the Bullet have such a large impact on society that precipitous actions are required as society attempts to deal with a series of crises.

A sequence of world-scale, climate-related events and wide acceptance of scientific thinking change worldwide views about climate change. Based on changing voter perceptions that the U.S. must join with other large economies to address climate-change issues, U.S. policy makers take strong actions. They increasingly impose regulations and standards that dictate many industry choices and lead to adverse economic outcomes in the short term. But it was considered a cost worth paying for longer-term benefits.

The policy changes take some steam out of demand for primary fuels. With slower economic growth, fuel prices moderate and begin to decline. Industries with large sunk costs in assets that are forced out of use enter a period of restructuring, but government investment eases some of the burden.

A shift to more sustainable lifestyles is forcibly pursued and politically supported, pushing some immature technologies into the market despite uncertainties regarding lifecycle costs and long-term benefits. Industry accepts the changes because voters demand them and government promises to buy-down the risk of these investments.

The U.S. decides to accept lower economic growth and puts pressure on other developing nations, especially China, to do likewise. Along with Western Europe, the U.S. imposes trade sanctions on nations with poor environmental standards. This slows the overall rate of global economic growth, but also protects jobs and promotes new investment in domestic industries.

Consumers believe that short-term sacrifices and changes in behavior and lifestyle will pay off in the long term by reducing the likelihood of adverse climate changes and moderating primary fuel price increases. Technology innovations in digital applications, bio-science, and other fields are directed toward creating products and services that support sustainable lifestyles.

The imposition of a high CO_2 tax slows economic growth and, without low-cost carbon capture and sequestration technologies, makes coal, oil, and gas very unattractive choices. Once alternatives supply technologies are in place, industry and consumers are prohibited from reverting to fossil fuels. Natural gas is allowed as a transition fuel but with quickly increasing constraints related to its greenhouse emissions.

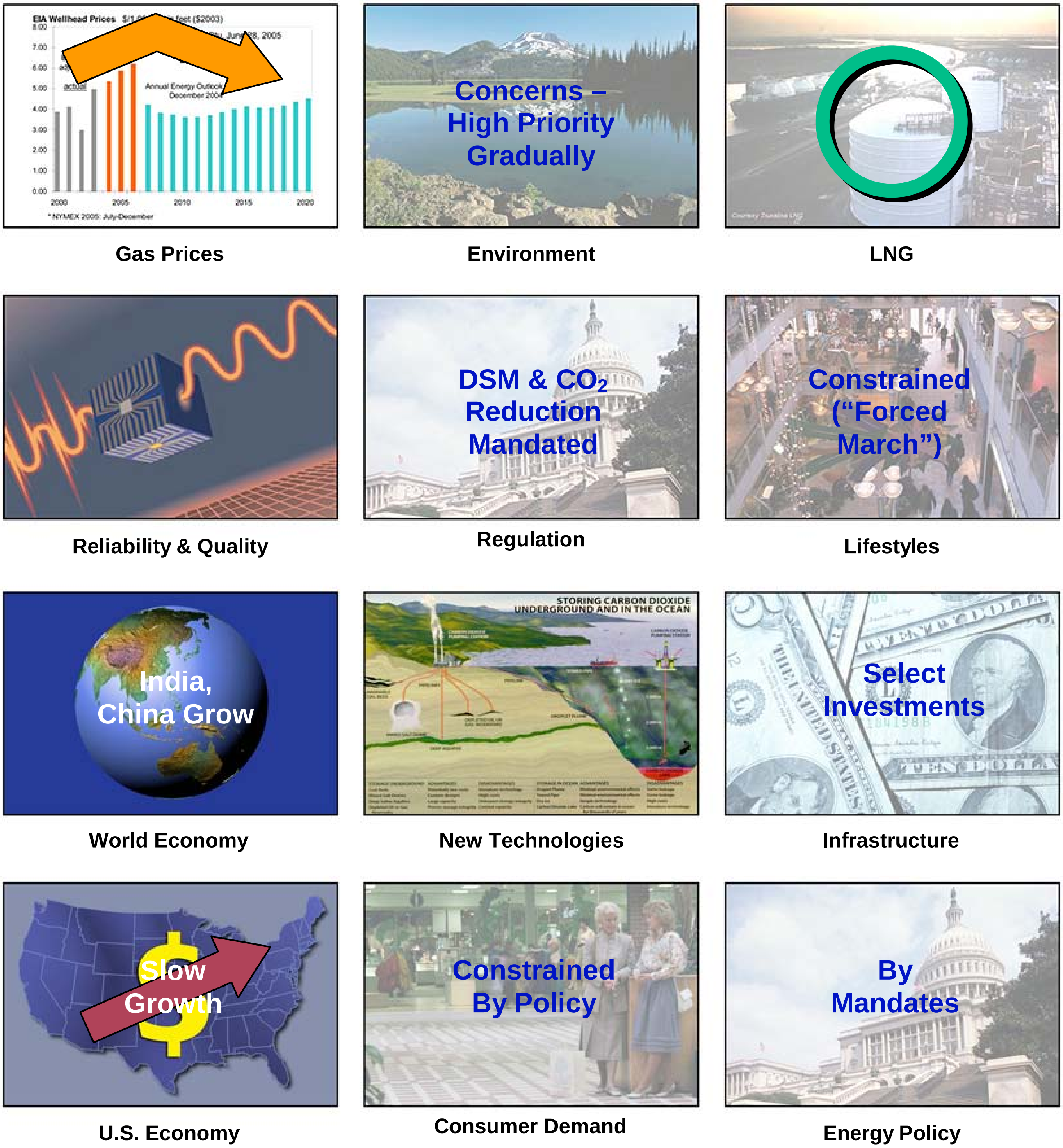


Figure 5-1
Overview of Biting the Bullet

Full Scenario Narrative

2005–2012

The costs—human, financial, material, and emotional—to the U.S. of having its Southern and coastal Eastern States battered each year change the thinking of citizens and politicians of all persuasions. Both scientific analysis and real world experience with climate change combine into a powerful political force that leads to swift policy changes and real actions. These place the U.S. on a dramatically different pathway in terms of how it addresses environmental issues.

Fortunately, the U.S. has been preparing for this eventuality. Technologies are available in the 2008 to 2010 timeframe that could enable the U.S. to accept significant commitments to carbon reduction. Even though the direct tie between storm frequency and climate change is somewhat tenuous, the accumulating scientific evidence in other areas supporting climate change concerns, combined with a growing public consensus that action is necessary, help galvanize energy policy makers and political leaders into aggressive action.

However, the key factors that prompted U.S. leadership to act were less tied to the debates about climate science and more tied to economic studies that showed that the U.S could tolerate more aggressive carbon reduction actions without damaging the U.S. economy or placing the U.S. in an untenable competitive situation with China or India. Even though China and India were not willing to move as quickly as the U.S., they were willing to take modest steps themselves to reduce CO_2 emissions. For all three countries, technology was the critical enabler. Advanced coal and nuclear plants were ready for deployment, carbon capture and sequestration R&D looked promising, and aggressive efficiency improvements were implemented.

The political climate in the U.S. was conducive to a nationwide initiative, driven from Washington DC and every state capital, to begin transforming U.S. energy infrastructure. After years of political wrangling, the public was anxious to see more bipartisan cooperation between the Administration, Congress and the states. Although many heated debates occurred over the pace of change, bipartisan support was strong for reducing fossil emissions, modernizing the U.S. infrastructure, and reducing dependence on foreign oil. The focus and commitments were targeted on transforming both the electric utility industry and the transportation sector.

These actions hit the electric power sector hard. Utilities that assumed they would be operating old fossil power plants for decades to come find themselves scrambling. Some plants have to be closed almost immediately and others must be phased out within a few years. Some utilities try to fight the new requirements with legal maneuvers, but swift judgments validating the new regulations quickly bring such actions to a halt. Others decide to accelerate conversion to natural gas and change investment plans to reflect that gas plants now receive more favorable treatment by government. Utility companies already making progress on meeting existing renewable portfolio standards are given some breathing room, but expect to see the standards rise from the 10% and 20% range to the 40% range. Utility companies are also committing to major new deployments of nuclear energy plants, with many new plants under construction by 2010 and even more plants on order.

By September 2009, Congress and the President agree upon the Climate Change and Energy Policy Act of 2009. It contains specific limitations on CO_2 emissions from power plants with a quickly escalating schedule of taxes and other penalties, a trading regime, and new powers for States. It requires a continued ratcheting down on allowable emissions of SO_X, NO_X, mercury, and particulates. The law also contains measures to encourage expansion of nuclear generation. Key provisions aimed at the transportation sector impact how Americans drive their cars.

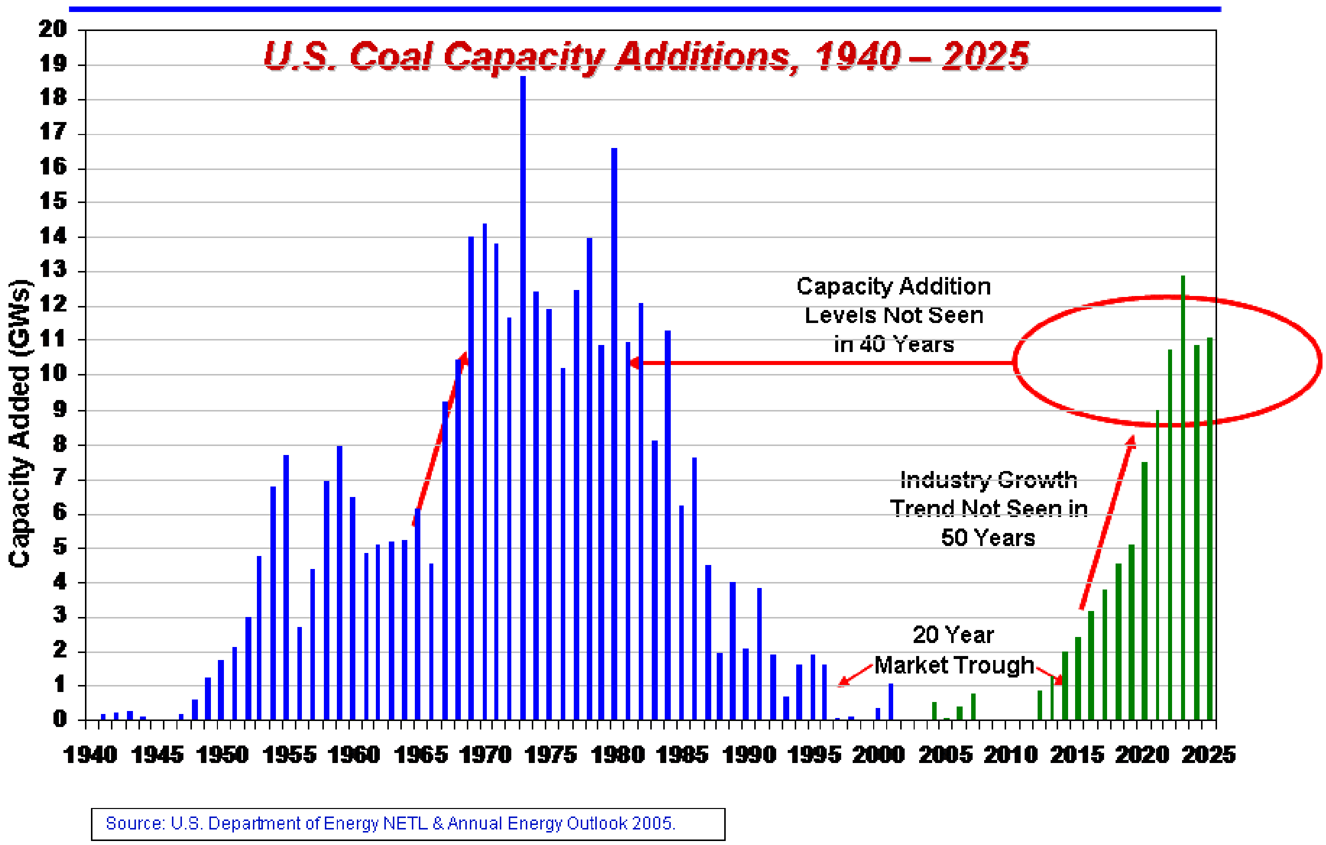


Figure 5-2
Age of Fossil Fuel Generation Fleet in the U.S., with the Majority of Coal Plants Over 30-Years Old

However, many Americans do not protest these changes because it gives them a way to participate directly in what they feel is a key issue facing the world. Just as Americans adjusted to recycling in the 1990s, they are open to modifying their behavior to preserve the environment. Americans begin paying a price for the transition as the annual GDP growth rate drops to the 2% range. Unemployment rises in some sectors and some regions are hit harder than others.

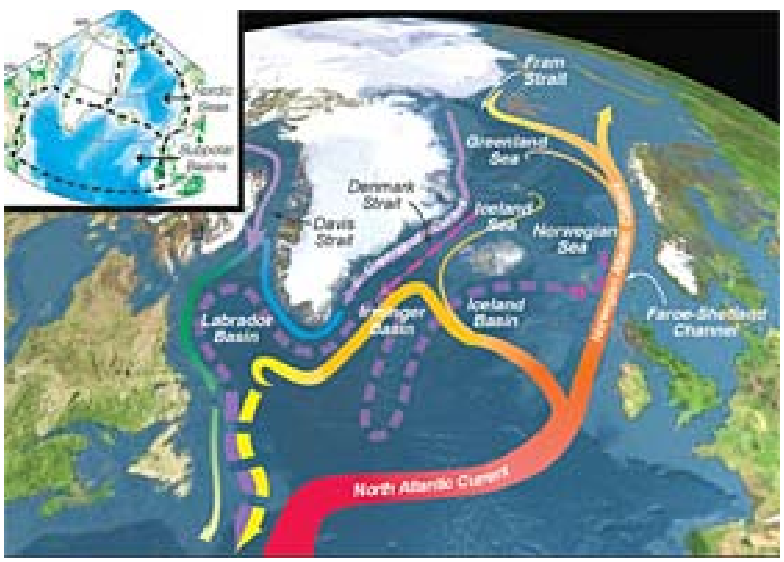
Global economic growth slows as a result of the changes in the U.S. Not only does the U.S. experience a mild recession from 2008 to 2010, but restrictions on imports and foreign direct investment by U.S. companies, as mandated in the Climate Change law, have significant impacts. U.S. business and industry are required to demand more stringent environmental requirements on imported goods and foreign operations. They are not allowed to bypass the intention of the new laws by skirting environmental requirements at overseas plants. Also, U.S.

workers are not penalized by having their jobs exported to places where dirty practices are allowed. European nations quickly follow the U.S. law with similar restrictions of their own. Some of these changes trigger factory closures in Asia that lead to involvement by the World Trade Organization. In every case, the U.S. position is upheld.

Natural gas and fossil fuel prices had been rising worldwide due to demand growth. U.S. leadership now views this as a plus, as investments in efficiency pay off and energy use is restrained. Over time, leaders feel that the transition to other alternatives will provide not only environmental benefits, but also declining dependency on fossil fuels for the nation. Without explicitly stating it, they also expect prices for fossil fuels to decline over the long term (for example, $8 to $10/MMBtu for natural gas).

2012–2019

Scientists are debating the shift in the ocean currents in the Atlantic and whether the world is entering a period of global cooling as a result of greenhouse gas emissions. The winter of 2012 is the coldest on record. Both Western Europe and the Northern tier of the U.S. are caught in the deepest snows and lowest temperatures ever. There is, essentially, no spring as snow does not leave the streets of New York until the first day of summer. As for its political consequences, the harsh winter further pounds into place stiff policies to address environmental concerns. European states lead an international charge to force all nations, particularly China but even poor developing nations, to reduce greenhouse gases.



Caption: Acting like a conveyer belt, the Atlantic current transports warm surface water toward the Poles and cool deep water toward the Equator. This circulation moves heat toward the Artic and helps moderate the wintertime temperatures in high-latitude Northern Hemisphere. Excessive amounts of fresh water, such as from the melting ice caps, could alter seawater density and in time affect the flow of the North Atlantic ocean current. Just how much extra freshwater it would take, known as the Atlantic Meridional Overturning Circulation, is a gray area of climate science. The estimates are from no chance for the pattern to shut down to 50% chance if global warming causes temperatures to climb by 7.2 to 9.0 degrees Fahrenheit.

Figure 5-3
Impact of a Significant Shift in the North Atlantic Ocean Current Flow

In the U.S., the political concern over addressing environmental issues leads to what many businesses feel is nationalization of their companies. Energy companies are required to function under price caps in many parts of the business, while still being held to reliability standards. Returns to investors collapse for some companies. Regulatory relief is offered in some cases, but executives are put on notice of criminal penalties for violating the law.

Following the 2012 election, the U.S. adopts a policy of pricing natural gas so that it remains the transition fuel of choice for power companies. Resulting federal regulations essentially cap prices at $10/MMBtu, which has the effect of reducing supplies, as well as forcing companies to find other alternatives. It also has the effect of implementing government. Low gas prices and high CO_2 prices combine to keep coal out of the running as a transition fuel.

The energy companies that are successful in meeting the fuel-neutral emissions targets are thriving during the transitions. Generally, those companies had a balanced portfolio of generation options and thus the most flexibility to design their long-term generation mix. In part due to R&D investment and expanded government incentives for non-emitting generation, implementation of wind energy and nuclear energy technologies rises to match large numbers of new orders by electric utility companies. Along with energy services companies that are finding new ways to improve energy efficiency, they are the new leaders of the emerging modern power sector. Based on their success, many economists predict the return to stable economic growth in the U.S. and building worldwide. The outlines of a sustainable world economy with new trade patterns shaping globalization are emerging.

Key to understanding the emerging dynamic are the trends in how people live everyday life. Energy use and prices are in the background, but shape lifestyle and consumer choices substantially. Information about energy prices and availability is readily accessible via the communications web, so it is easier to decide which actions to take and when. The net effect is a more efficient economy and less demand for power. Electricity is more likely to come from a mix of non-fossil fueled generation, either distributed or centralized, that could be owned by utilities or consumers. Use of fossil-fueled power is limited in duration and carries a significant price penalty, in many cases transferred directly to consumers through price signals.

By 2018, Americans and their leaders are getting “control over the situation.” The President delivers a report stating that the U.S. economy is now functioning at a sustainable level of growth while emitting 10% less greenhouse gas emissions than in 2005. “This,” he says, “is progress all Americans can be proud of and we expect it to continue.” But he is also clear that more progress is needed to overcome some of the long-term effects of previous environmental damage. Violent weather-related events are still likely, and concerns remain about agriculture, land use, disease vectors, and other climate effects, but hopefully these will moderate over time. He challenges other countries to follow the U.S. lead.

2020–2025

The headline grabbing news at the beginning of the year 2020 is a forecast of a drop in world oil and natural gas demand announced by the International Energy Agency. However, to energy analysts and many government leaders it comes as no surprise. The fact that prices fall so quickly and stay low without a significant demand response is even more telling. Industrial leaders boldly say that fossil fuels should be used only in a limited number of ways where they provide the most benefit and can be used most efficiently. Oil still holds a dominant position in transportation markets, but is being used much more efficiently and is supplemented by biofuels, so much so that oil's greenhouse gas emissions are approaching a sustainable level.

What is most impressive to electric-industry observers is how rapidly nuclear power expanded to limit the use of natural gas generation. Renewable energy also made modest contributions to limiting use of natural gas. Some infrastructure issues remain, especially around managing now super-sophisticated transmission networks, but overall the industry is performing at a high level. Expectations are also positive about the next generations of machines being brought into service. Solar and wind energy systems and the emerging technologies around energy storage portend another evolution in features for power use.

The progress in the energy sector also suggests a need to modernize the regulations that pressed the industry into action. Some oversight could be relaxed and market competitions could be allowed to thrive more freely in certain areas. However, natural gas market and price regulations will remain intact. Within the natural gas supply industry, an emerging issue is regulation on shutting down and mothballing LNG plants.

All is not entirely smooth sailing, however, as a minority of environmentalists are beginning to point out emerging issues with some of the equipment now widely in use. Disposing of some equipment is raising issues around toxic chemicals. Obsolete wind turbines are left to rust on hill sides and are unsafe for animals. These same analysts also point out that storms are as severe as ever.

The U.S. economy is still the largest in the world and now a successful exporter of high-efficiency end-use energy equipment. U.S. trade patterns are shifting as it is becoming significantly more energy independent. Population growth is the key driver in rising energy demand, but even this is manageable due to efficiency and cleanliness of the U.S. energy base. Though these changes were muscled into place by a government that was sometimes ahead of industry, in the long term what has emerged is a sounder economy with products and services that consumers find better to use and companies find profitable to sell.

Areas of Technology Development

The world of Biting the Bullet in the energy sector is characterized by high and rising costs to meet environmental requirements that eventually drive shifts and structural changes that moderate primary fuel costs. This world is driven by a strong sense that technology-based solutions are needed to meet climate change and environmental quality issues. Government and industry programs focus on efficiency, nuclear energy, renewables, and other clean technologies. Central station generation faces strong pressures to shift to more clean and efficient technologies, but the electricity industry is also receives guidance and support from regulatory authorities interested in ensuring results. Large-scale solutions that work are supported, and nuclear power grows at an impressive rate in this world.

Table 5-1
Areas of Technology Development—Biting the Bullet

Technology Themes	Technology Gaps		
Sustain Nuclear Fleet	Further development of advanced fuel cycles	Improved materials for nuclear retrofits	Resolve waste issues
Advanced Coal	Further increase in IGCC efficiency is critical	Environmental dispatch of fossil plants	Ability of IGCC to help keep gas prices in check
Sustain Gas Generation	Use in firming intermittent wind	Solid oxide fuel cells—60% efficiency	Infrastructure sized for both power and winter heating peaks
Carbon Capture and Sequestration	Technologies for carbon capture, transport and storage	CO_2 capture from coal combustion technology	EOR for CO_2 injection
Environmental Emissions	Advanced scrubbing for CO_2	Availability and adequacy of water supply	
Renewable Resources	Vast field of energy capture opportunities	RPS approaching 30%	Integrate renewables and storage
Distributed Generation	Develop and build polygeneration plants	High-efficiency home use or plant devices	Develop and deploy integrated energy parks
Energy Storage	Pilot-plant studies and full-scale demos of storage applications	Integrate gas and electricity storage with DER strategy	Continued reduction of the cost of all storage technologies
Transmission Portfolio	Changing topology of transmission	Prevent fault propagation	Active power factor control using DC
End-Use Efficiency Improvement	Backpressure turbines at pressure-reducing valves	Advanced CHP technology	Electricity replaces gas in many applications
Customer Portal	Smart sensors in appliances and meters	PQ data acquisition available at portal	Ubiquitous DC in homes and offices
Distribution Automation	Assess impact of growth in microgrids	Conservation resulting from real-time price signals	Advances in understanding of large networks
Building-Integrated Energy Systems	CHP and DC in the home	Photovoltaic roofing tiles and windows	“Zero energy” buildings
Plug Hybrid Electric Vehicle	Park & ride cars that store electricity and shave peaks	Reliable estimates of CO_2 benefits	Truck stop electrification

6
EVOLUTION OF ELECTRIC INDUSTRY IN CONTEXT OF THE SCENARIOS

In Chapters 2 through 5, we describe the scenarios in detail. With this background, we can now use each scenario space as a possible state of conditions for the short- to medium- and long-term. We can imagine moving from one state to another over time. In addition, certain geographical areas of the U.S. (or the world) may be in different scenarios spaces and that we can transition from one to the other. We show three such pathways below. To describe movement from one quadrant to another or within a quadrant, we use directional descriptions such as north, south, etc., as if the quadrants were a map.

- Assuming that conditions at the end of 2005 for most of the U.S. approximate what exists in the SE quadrant (Digging in Our Heels—relatively high fuel prices and low cost for externalities), then we can imagine some northward movement toward Double Whammy as the cost of environmental externalities increases while fuel prices continue to increase.
- We can imagine movement from the SE (Digging in Our Heels) to the West (Supply to the Rescue) if fuel prices decline as new supply is brought on and the cost of environmental externalities remains low.
- We can imagine movement to the NW (Biting the Bullet) if, overtime, a combination of rising costs for externalities combines with falling demand for traditional fuels.

These movements are not the only ones imaginable, especially over a 20-year period. Also, specific power markets may perceive that their current conditions are most similar to different scenario quadrants (for example some parts of the U.S. or the world may see themselves in the NE or SW quadrants in 2005). New England, California, and the European Union in particular appear to be in the NE quadrant of the Double Whammy, with high energy prices and a strong commitment to environmental improvements. Moreover, even though Supply to the Rescue may seem to be wildly improbable given recent events, we can look back to the late 1990s to see an example of nationwide low gas prices coupled with minimal environmental sensitivity.

As a tool for thinking about the long term and generating conversation, readers may want to imagine various paths (for example, cycling back and forth between two scenarios) over a period of several years.

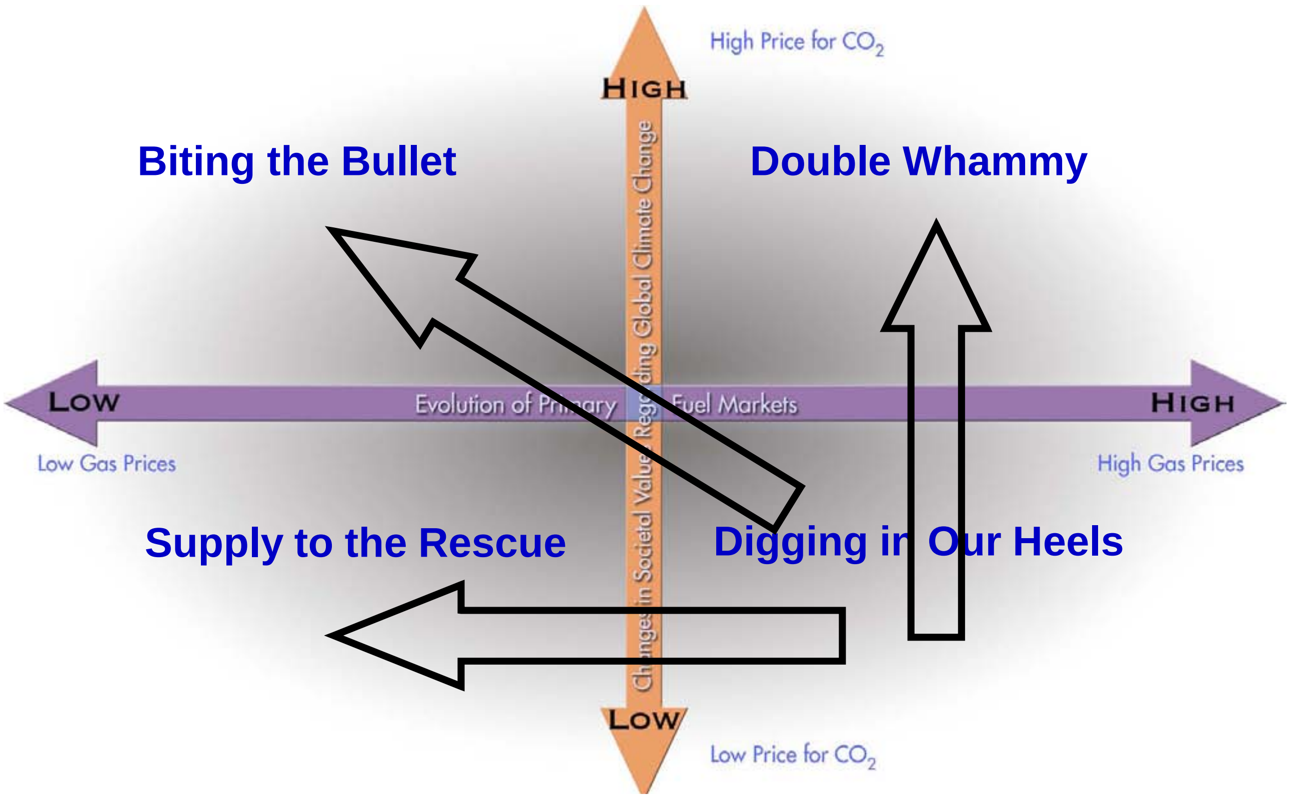


Figure 6-1
Evolution of Scenario Matrix

7
NEXT STEPS

As we mention at the beginning of this report, the results of this scenario analysis will be an input into the analysis supporting the next *EPRI Technology Roadmap*. To get a start at this, the robust and priority technology development areas presented below will be used.

Top 10 Technology Recommendations

1. **Customer Portal Investment.** The portal provides the physical and logical links that allow communication of electronic messages from the external network to consumer networks and intelligent equipment.
2. **Distribution Automation.** Integrated energy and communications system architecture; fault anticipation technology to forecast grid failures; adaptive islanding and storage technology.
3. **Carbon Capture and Sequestration**. Breakthrough technologies that reduce the economic impact of removing CO_2 from fossil generation plants; pilot-scale and full-size demonstrations of these advances.
4. **Advanced Coal and Nuclear Generation.** Low-emission designs of integrated gasification combined cycle (IGCC) generation for coal; demonstration of a stable licensing process and cost-effective deployment of advanced light water reactors; technology basis for the helium reactor.
5. **Environmental Emissions.** Control of a wide range of gaseous, aqueous, and solid pollutants that are produced as byproducts of electricity generation and use. Examples include SO_2, NO_X, fine particles, mercury compounds, and CO_2 for fossil generation.
6. **Energy Storage.** Large-scale, low-cost storage systems, focusing on advanced technologies such as flow batteries, flywheels, ultracapacitors, and compressed air energy storage.
7. **Transmission Portfolio.** Planning for expanding and enhancing the North American transmission grid; planning tools to assess the location, timing, and size of new power plants and transmission lines; integration of generation and transmission system upgrades.
8. **Sustain Existing Nuclear Fleet.** Application of reliability-focused technologies to resolve issues and manage assets; managing the transition to advanced light water reactors.
9. **Training and Simplification.** Develop and deploy tools for managing a power industry staffed with individuals who are not as well-trained as their predecessors.
10. **Sustain Existing Gas and Coal Fleets.** Advanced technologies for operating and maintaining the current fleet of fossil power plants, including asset management tools; address the need to meet emissions targets for these plants.

Our experience with scenarios is that they have a shelf life of about two to three years. During that time period, developments in markets, the economy, and politics tend to make other uncertainties and questions more relevant for scenario analysis. The expiring scenarios will have served as a learning tool by providing perspective and some focus on drivers of change.

The scenarios in this report, based on conditions at the time of their writing (and the perspectives of the team involved in their development), focus on a utility industry that has few external innovators or new entrants. This may prove to be short-sighted in an age of constant technological innovation coming from fields such as nanotechnology, information and communications, bio-science (genetics), and new materials. Over the next few years, it will be a prudent next step to watch for developments in these areas and for their implications in the energy sector.

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