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Energy and National Security

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Energy and National Security

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Abstract

On May 19 and 20, 2003, thirty-some members of Sandia staff and management met to discuss the long-term connections between energy and national security. Three broad security topics were explored:

I. Global and U.S. economic dependence on oil (and gas);
II. Potential security implications of global climate change; and
III. Vulnerabilities of the U.S. domestic energy infrastructure.

This report, rather than being a transcript of the workshop, represents a synthesis of background information used in the workshop, ideas that emerged in the discussions, and *ex post facto* analysis of the discussions. Each of the three subjects discussed at this workshop has significant U.S. national security implications. Each has substantial technology components. Each appears a legitimate area of concern for a national security laboratory with relevant technology capabilities. For the laboratory to play a meaningful role in contributing to solutions to national problems such as these, it needs to understand the political, economic, and social environments in which it expects its work to be accepted and used. In addition, it should be noted that the problems of oil dependency and climate change are not amenable to solution by the policies of any one nation—even the one that is currently the largest single energy consumer. Therefore, views, concerns, policies, and plans of other countries will do much to determine which solutions might work and which might not.

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Contents

Acknowledgments 4
Contents 5
Executive Summary 7
Introduction 11
International Oil and Gas Dependence 11
Context 11
Threats, Risks, Uncertainties 13
Disruption Risks 13
Vulnerabilities 15
Uncertainties 16
Solution Options 16
Strategic Reserves 16
Regime Support 17
Military Deterrence or Action 17
Supply Diversification 18
Conservation and Efficiency 18
Alternatives to Oil 19
Observations on Oil Supply Disruption Solutions 20
Global Climate Change 21
Context 21
Threats, Risks, Uncertainties 22
Solution Options 23
Efficiency 23
Carbon Sequestration 24
Alternative Energy Sources 24
Observations on Climate Change Mitigation Solutions 25
Infrastructure Vulnerabilities 25
Context 25
Threats, Risks, Uncertainties 26
Solution Options 27
Observations on Infrastructure Vulnerabilities 29
The Scope of the Problems 29
Conclusion: Some Issues for Sandia 32
Understand the Human Dimensions 34
Think Globally 34
Appendix I: Summaries of Pre-Fest Readings 35
Appendix II: Links to Additional Background Reading 56

Energy and National Security

Executive Summary

On May 19 and 20, 2003, thirty-some members of Sandia staff and management met to discuss the long-term connections between energy and national security. Three broad security topics were explored:

I. Global and U.S. economic dependence on oil (and gas);

II. Potential security implications of global climate change; and

III. Vulnerabilities of the U.S. domestic energy infrastructure.

This report, rather than being a transcript of the workshop, represents a synthesis of background information used in the workshop, ideas that emerged in the discussions, and *ex post facto* analysis of the discussions.

Oil and Gas Dependence

As the world's population and economy grow, so will energy consumption—and with it global dependence on oil from the Middle East (where the largest reserves lie). Although oil is projected to continue to dominate world energy use (particularly in the transportation sector), natural gas is playing a growing role, and its disruption could also have increasingly significant security consequences.

The structure of the international oil market is such that oil embargoes directed at specific consumer nations (such as the 1973 embargo against the U.S.) are unlikely. But political revolution, terrorism, sabotage, and warfare all have the potential to impose economically damaging supply disruptions. The degree of damage to all oil importing countries (and countries that trade with them) would depend in part on the oil intensity (amount of oil used per unit of GDP) of their economies.

Classes of measures to defend against import supply disruptions include:

- maintenance of strategic reserves;
- support of government regimes likely to maintain production;
- military deterrence, protection, or intervention to secure production sources, facilities, and supply lines;
- diversification of production sources;

- reduction of oil intensity through conservation or through more efficient energy use; and

- development and deployment of alternative energy sources.

Oil dependence is a global issue. Even if the U. S. were to substantially reduce the oil intensity of its economy, the economic risks to the U.S. of world oil supply disruptions would still be large unless its direct and indirect trading partners also reduced their vulnerabilities.

Oil dependence is also a long-term issue, since it is not feasible to completely eliminate it in the next 20-40 years; the question then becomes, how much independence should be pursued, at what pace and at what economic, social, and political cost?

Global Climate Change

There is broad (but not universal) scientific agreement that the global climate will continue to warm in the 21st century, and that human-generated greenhouse gases, particularly carbon dioxide, are playing a role in this warming. Many uncertainties remain about the probability, amount, timing, causes, and degree of impact of climate change. Of additional concern is the possibility that very abrupt climatic changes could occur (as they have in the past) that would make human adaptation all the more difficult.

Though climate change could be beneficial to some people in some places, it could also impose great environmental stresses on others, exacerbating existing shortages in water, shifting agricultural patterns, spreading the range of tropical diseases, and increasing the numbers of violent weather events. Developing countries may be especially vulnerable to these effects. The resulting societal stresses might, in turn, lead to "failed" states, civil unrest, support for terrorism, interstate conflicts, or increased demands on international aid resources. Unequivocal evidence of warming might also lead to increased domestic and international demands to cut greenhouse gas emissions by reducing fossil fuel consumption.

Many believe that action to stabilize atmospheric greenhouse gas (GHG) concentrations by significantly lowering emissions can mitigate how much global warming will occur. Most mitigation interest centers on reducing the CO_2 emissions from the combustion of fossil fuels (which in the U.S. accounts for 98% of emissions). Proposed measures for doing so include increased energy efficiency, carbon sequestration, and alternative energy sources. (Some have also proposed climate engineering to counter the greenhouse effect.) There is substantial overlap between the sets of solutions applicable to reducing oil dependence and to reducing CO_2 emissions. And, in both cases, no single technical solution is likely to be adequate, so evaluating combinations of solutions will be essential.

Since some climate change is bound to occur in any case, adapting to the consequences will have to become part of national and international development planning.

Infrastructure Vulnerability

Although the energy intensity of the U.S. economy has been declining modestly for the past few decades, energy is still vital to agriculture, water utilities, commerce, manufacturing, employment, health care, education, telecommunications, information systems, and transportation. These are all subject to disruption if there is damage (whether accidental or intentional) to the networks and facilities that supply oil, natural gas, and electricity. And these systems (and the control systems for them) do appear to be vulnerable to such damage. The business practices, regulatory environment, and economics of the energy industries have inadvertently increased vulnerabilities both to natural disasters and to terrorist attacks.

Options for reducing the vulnerability of the domestic energy infrastructure include:

- reduce the energy intensity of the economy;
- diversify energy sources and applications;
- move to more distributed power generation and transmission systems;
- devise energy storage technologies and load-leveling technologies to enhance system resilience;
- build fault-tolerant and self-healing infrastructure elements;
- establish a national regulatory framework that emphasizes system integrity and security; and
- encourage utility officials to analyze their system vulnerabilities and interdependencies, and prepare for possible attacks or other disruptions.

It is difficult to produce plausible quantitative threat assessments, but given the combination of vulnerabilities to nature, accident, or attack, there is an argument for a national effort to ameliorate them.

The Challenge of Problem Definition

The three major problem areas discussed at the workshop share, for the most part, several challenging characteristics:

- they are worldwide in scope;
- they involve public goods and market externalities;
- their solutions (or neglect) involve inter-generational transfers of costs and consequences;
- they involve multiple decision-makers;
- different parties contribute to them and suffer their consequences in different ways;

- policies to address them will interact significantly with other policies;
- there are pervasive uncertainties in assessing them and their solutions; and
- their inertia is such that they can be turned around only in decades.

Sociological, psychological, political, economic, and cultural factors pervade the problems, and any proposed solutions will somehow have to integrate those factors into their development and implementation. Several participants in the workshop underscored that doing so would be important in any work done in the three problem areas.

Finally, although Sandia may play various contributing roles in addressing these problems, it should take a worldwide view that relates international security to U.S. national security and hence to Sandia activities.

Introduction

On May 19 and 20, 2003, thirty-some members of Sandia staff and management met to discuss the long-term connections between energy and national security. Three broad security topics were explored:

I. Global and U.S. economic dependency on oil;

II. Potential security implications of global climate change; and

III. Vulnerabilities of the U.S. domestic energy infrastructure.

Participants discussed both the potential security "threats" in each area and the problem of assessing how likely and intense those threats might be. They also discussed various technologies that have been proposed to ameliorate the threats in one way or another.

The purpose of the EnergyFest was not to arrive at definitive conclusions, but to explore the thinking of Sandians on these subjects, to identify subjects for further research and learning, and to set the stage for a series of additional workshops that would bring in external experts to shed further light on the issues. The entire process is intended to contribute both to national energy policy deliberations and to support Sandia decision-making in developing a long-range research portfolio for energy.

The format of the discussions was that used in previous Advanced Concepts Group "fests": both full-group sessions and small break-out groups of about a dozen participants discussing assigned problems, with reports back to the full group. This report, however, is not a transcript of the workshop. Rather, it represents a synthesis of background information used in the workshop, ideas that emerged in the discussions, and *ex post facto* analysis of the discussions.

International Oil and Gas Dependence

Context

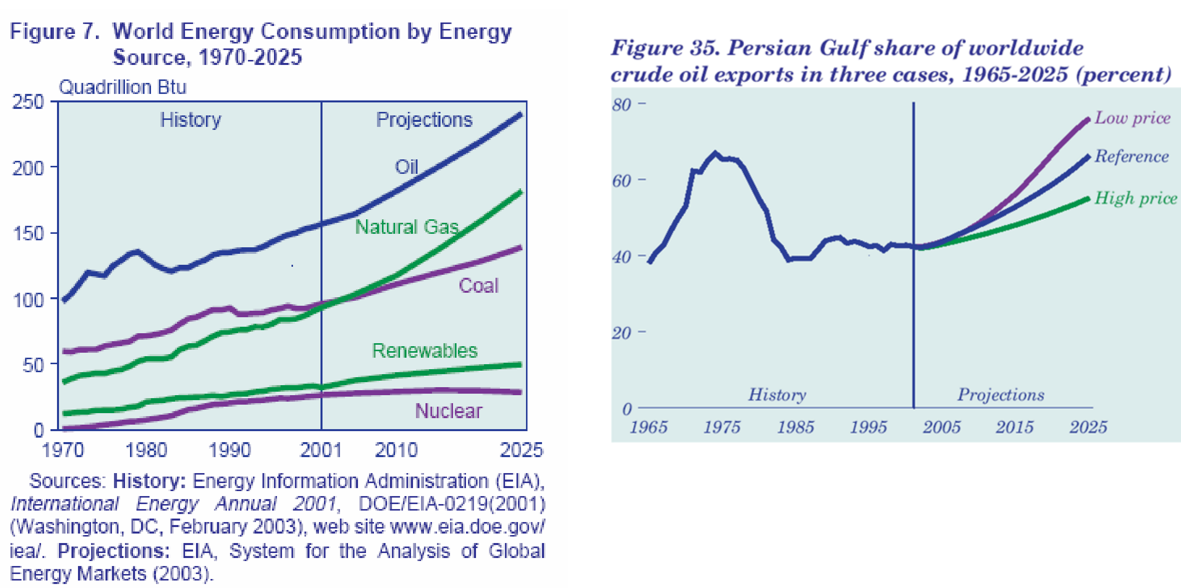
The U.S. Department of Energy's Energy Information Administration (EIA), as well as the International Energy Agency, projects that oil will dominate global energy consumption for at least the next several decades. As the world's population and economy grow, so will energy consumption. Global dependence on oil from the Middle East (where the largest reserves lie) will grow accordingly. If existing patterns persist, Saudi Arabian oil will continue to be of central importance, not only because Saudi Arabia has the Middle East's largest reserves, but because Saudi surplus oil production capacity has put that country in a unique position to rapidly increase or decrease oil production capacity to influence world oil prices.

From the standpoint of Middle East oil producers (especially Saudi Arabia), who have very large reserves and expect to sell oil for a very long time, constricting supply to raise prices has its limits as a rational strategy. Higher prices mean higher revenues as long as the quantities sold remain high. But higher costs also induce changes in consumer economies: inflation increases and economic productivity decreases, lessening the demand for oil. Higher prices also make diversified sources of oil and alternative sources of energy economically more competitive, thus threatening to lower the long-run demand for OPEC oil.

Conversely, increasing oil production to lower prices means lower revenue per barrel of oil sold, but has the benefit of encouraging consumption and decreasing the competitiveness of more expensively produced oil and alternative energy sources. Thus the long-run dependence of consumers on Middle East oil is enhanced.

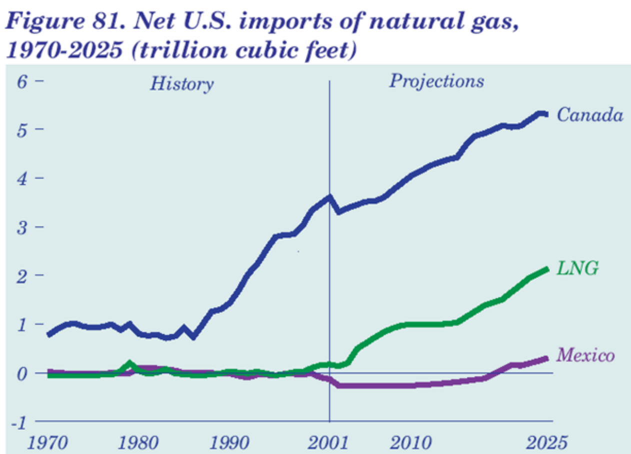
Although oil is projected to continue to dominate world energy use, natural gas is playing a growing role, and its disruption could have increasingly significant security consequences. The EIA projects that the bulk of growing U.S. natural gas imports over the next 20 years will come from Canada—presumably a relatively secure source, if in fact Canadian production increases to meet U.S. demand. If the U.S. not only increases the contribution of natural gas to electric power generation, as forecast, but also moves to a hydrogen economy in which natural gas is used to produce hydrogen gas, the need for imports could grow still larger. Such growth could also increase the vulnerabilities associated with the importation of liquid natural gas from sources outside North America.

Figure 1: World Energy Consumption and Persian Gulf Oil Exports



Meanwhile, European dependence on Russian natural gas is considerable, making their economies vulnerable to disruption of that supply. Japanese and Chinese imports of natural gas will also grow significantly.

Figure 2: U.S. Imports of Natural Gas to Grow



Natural gas supplies from western Canada and the Scotian Shelf in the offshore Atlantic are expected to account for most of the increase in U.S. imports. In addition, the reference case projects that a new natural gas pipeline from the MacKenzie Delta will begin operation in 2016. Net imports from Canada are projected to provide 15 percent of total U.S. supply in 2025 in the reference case, about the same as in 2001.

LNG imports are expected to increase to 2.1 trillion cubic feet per year in 2025, equal to 6 percent of total U.S. gas supply. The projected 2025 LNG import level is based on expectations that all four existing LNG import facilities will be fully reopened and expanded—and that three new facilities will be constructed in the Gulf of Mexico and Florida areas—by 2025. The three new LNG facilities are expected to have a combined gas delivery rate of 2 billion cubic feet per day.

… Mexico is projected to remain a net importer of U.S. natural gas through 2019. After 2019, Mexican natural gas imports are expected to come from an LNG import terminal built in Baja California, Mexico. By 2025, the United States is expected to import about 300 billion cubic feet of natural gas from Mexico per year.

Source: EIA *Annual Energy Outlook, 2003*

Threats, Risks, Uncertainties

(This section refers primarily to threats to oil imports. As natural gas imports increase in the future, many of the same concepts could well apply.)

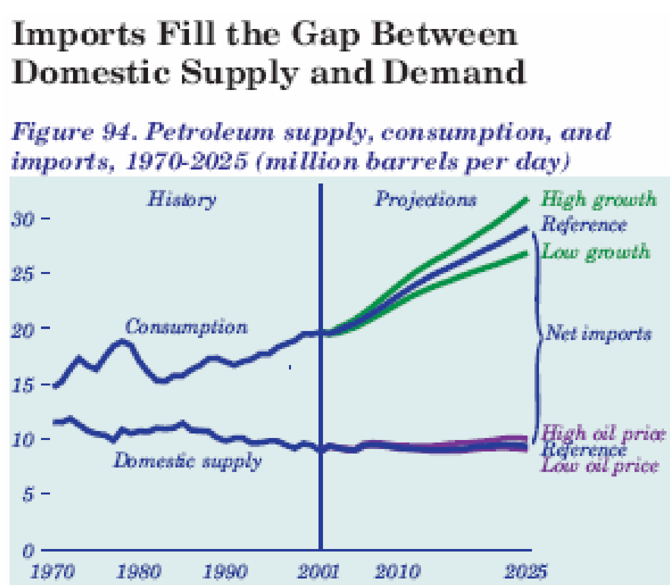
Disruption Risks

In 2001, world oil imports were 56.3 million bbl/d; the EIA forecasts that by 2025, that figure could be 94.6 bbl/d. The structure of the international oil market is such that oil embargoes directed at specific consumer nations (such as the 1973 embargo against the U.S.) are unlikely. A decision to dramatically reduce supply would generally not be in the interest of a producing country, for the reasons cited above. However, such a decision does not appear completely out of the question. For example, suppose a radical Islamist regime took over Saudi Arabia, and decided that that country should return to traditional ways rather than attempting to "modernize" economically. (For a recent historical example of a regime that was willing to accept reduced oil revenues for political purposes, consider the Iraqi government from 1991-2003).

A supply disruption need not come from an intentional decision to reduce production. Terrorists or revolutionaries might sabotage production facilities to try to bring down the ruling regime. Sabotage that managed to contaminate such facilities with radiological materials might prevent production for a particularly long time. Again, Saudi Arabia stands out as the most important region of threat, not only because of the size of its oil exports, but also because of its internal production chokepoints and because of the uncertain long-term viability of the ruling family. One could also imagine, later if not sooner, a more traditional military conflict between, say, Iran and Saudi Arabia that led to damage to the production facilities of both. A war might also close the Strait of Hormuz, through which some 13 million barrels of oil per day (bbl/d) pass.

Wars that closed other oil transport chokepoints (whether sea lanes or pipelines) could also severely constrict the worldwide flow of oil: Bab el-Mandab (Red Sea to Arabian Sea, 3.3 million bbl/d); Turkish Straits (2 million bbl/d); Strait of Malacca (Indian Ocean to South China Sea, 10.3 million bbl/d); Suez Canal/Sumed Pipeline (Red Sea to Mediterranean Sea, 3.8 million bbl/d.)

Figure 3: Projected Growth of U.S. Oil Imports



Source: EIA *Annual Energy Outlook, 2003*

Vulnerabilities

Disruptions of oil supply for whatever reason do have considerable potential for damaging the economies of all the countries that must buy or sell oil on the international market. Higher oil prices increase inflation and reduce economic growth for the buyers. Lost sales cost producers revenue. For a given degree of extent and length of disruption, the degree of damage will depend in part on the timing of the disruption, in part on the energy intensity, and, in particular, the oil intensity of the consuming economies, in part on the interdependence among those economies, and in part on the resilience and recovery capacity of the affected nations.

Timing and Duration

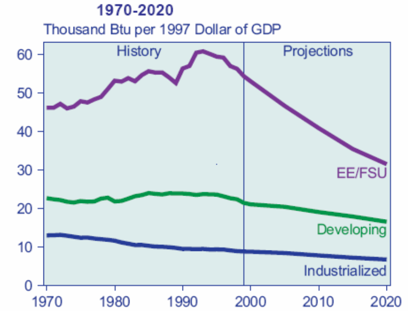
Disruption-caused high oil prices might be particularly damaging in winter to the northeastern U.S., with its heavy reliance on heating oil. Prolonged high prices during a period of already high inflation or low economic growth would be more damaging to any country than they would if some economic cushioning were present.

Energy and Oil Intensity

According to an EIA estimate, for every one million bbl/d of oil supply disrupted and not made up for by other supplies, world oil prices might increase $3-$5 dollar per barrel. Over months or years, a 10% rise in the price of oil could lower the U.S. real GDP growth rate by .05 to 1.0 percent.[1] The effects of oil (and other energy) prices on an economy will depend in part on the "energy intensity"—the amount of energy used per unit of GDP. As **Figure 4** shows, the energy and oil intensities of most countries are projected to decline modestly over the next 20 years, with developing countries' economies remaining more energy intensive than those of the industrialized countries. Many developing countries are also vulnerable to price rises because oil imports constitute a higher proportion of their total imports, thus consuming larger amounts of their foreign exchange funds.

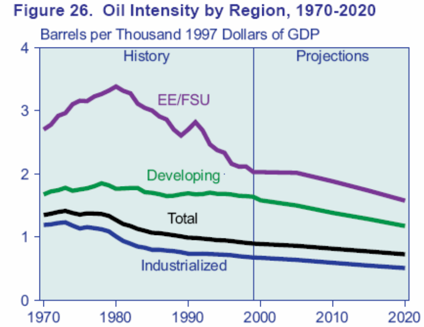
Figure 4: Energy and Oil Intensities

Figure 22. World Energy Intensity by Region, 1970-2020



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, February 2001). **Projections:** EIA, World Energy Projection System (2002).

Figure 26. Oil Intensity by Region, 1970-2020



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, February 2001). **Projections:** EIA, World Energy Projection System (2002).

Source: *EIA International Energy Outlook*, *2003*

[1] See http://www.eia.doe.gov/security/rule.html#size

Uncertainties

It is possible to make some quantitative estimates of the vulnerabilities of the U.S. and world economies to oil supply disruptions. It is possible, as above, to identify plausible ways in which supply could be disrupted. It does not appear possible, however, to make credible, quantifiable estimates of the *probability* of such disruptions, in the near term, let alone 20 to 40 years out.

Solution Options

Classes of measures to defend against import supply disruptions include:

- maintenance of strategic reserves;
- support of government regimes likely to maintain production;
- military deterrence, protection, or intervention to secure production sources and facilities;
- diversification of production sources;
- reduction of oil intensity through conservation or through more efficient energy use; and
- development and deployment of alternatives to oil (or gas).

Note that none of these measures seems likely to emerge from business-as-usual market processes (except when disruptions are either already occurring, or become very probable, so as to change market incentives). Thus implementation of these measures will usually require public policy decisions. In the case of the first three, they would be foreign and military policy decisions; in the case of the latter three, they would be legal, regulatory, or governmental subsidy decisions.

Strategic Reserves

The cheapest, earliest available insurance against oil supply disruptions is to maintain reserves to replace disrupted supplies. Members of the International Energy Agency have agreed to maintain reserve supplies (including both public and private stocks) equal to 90 days of supply. Not all members have maintained this level. As of June 2003, U.S. public stocks (the Strategic Petroleum Reserve) held about 53 days of imports plus additional privately held stocks.[2] As oil consumption increases, so does the difficulty of storing reserves to match.

[2] See http://www.fe.doe.gov/spr/spr_facts.shtml

Regime Support

During the Cold War, the United States established special relationships with the governments of Saudi Arabia, Iran, and others that were intended in part to keep them from falling under the sway of the Soviet Union. Even though the U.S. itself was not heavily dependent on oil imports in the 1940s, '50s, and '60s, the U.S. feared that the Soviet Union might shut off oil supplies to strangle U.S.-allied economies.[3] Later, Saudi Arabia nationalized its oil concessions and Iran was taken over by a hostile regime. For the most part, the oil continued to flow, except when Saudi-led OPEC embargoed oil to the U.S. in 1973 (which would be difficult to duplicate today).

As noted above, economic interests today weigh strongly against attempted oil embargoes (though the U.S. has used oil *buying* and *investment* embargoes against Iraq and Iran). Some argue, however, that it would be in the U.S. interest to try to move the Saudi Arabian regime into a more modern and democratic mode to forestall disruptive actions by radical Islamist forces.

Military Deterrence or Action

Did the U.S. invade Iraq to “take over” its oil reserves, as some have asserted? Certainly the U.S. wished to remove the Saddam Hussein regime from access to Iraqi oil wealth, which enabled international mischief on his part. (But lack of access to Iraqi oil in the international economy resulted more from the U.N. embargo than from Hussein’s unwillingness to sell the oil.) Still, should a regime that refuses to sell its oil to the world take over a major oil-producing nation[4], military intervention might be an option. Intervening to suppress insurgent forces that threaten to disrupt production facilities is another possibility (the U.S. is assisting Venezuela in its attempt to stop guerillas who have been sabotaging oil pipelines). Intervening to stop a regional war in which production facilities might be damaged might protect against that kind of disruption. And the world’s major navy, the U.S. Navy, also has an implicit mission of keeping the major sea-lanes open to commercial traffic, including oil transportation.

From a technology perspective, then, military technologies that help the U.S. and its allies conduct such operations more successfully could be viewed as oil supply security measures.

Some argue that a substantial proportion of U.S. military expenditures should be considered as devoted to oil protection. An extension of this argument is that domestic oil prices should reflect the military costs, perhaps through a tax. With such higher oil costs, consumers might switch to other fuels or be willing to purchase more efficient vehicles. Others argue that U.S. worldwide interests are such that even if the concentration of oil in the Middle East did not exist, U.S. military requirements would be about the same.

Another technology approach brought up at the workshop would constitute a non-military deterrence of, or response to, violent production disruptions. The idea is to build

[3] Some might also argue that the U.S. was also interested in the security of U.S. oil company interests in those countries.
[4] Particularly Saudi Arabia, but other producers supply significant, though not such decisive, shares of the world’s oil exports.

"recovery-oriented engineering" into existing and new facilities, making them easier to bring back on line if they are attacked. This might be combined with maintaining an emergency response team that could be sent quickly to damaged facilities to restore function. This concept of course implies the cooperation of the producing country in the engineering, and a secure environment for the response team in the event of conflict or sabotage.

Supply Diversification

Most of the world's oil reserves happen to be in the Persian Gulf, but the further development of other regional sources of oil can to some extent alleviate the risks of dependence on a single volatile region. Candidates for increased export include Russia, the Caspian Sea region, and the oil shales and tar sands of Canada. Exploration and extraction technologies that make more diverse sources economically competitive could ultimately reduce the impact of disruptions from any single source.

Conservation and Efficiency

Conservation—cutting back on energy use may help control energy prices by cutting back on total demand. If the cutting back were in areas that are less economically productive, then more of the supply would be available for applications that are more so. As an emergency response to disruptions, conservation could help limit energy price rises.

Increased energy efficiency, on the other hand, means getting the same outputs for less. As noted above, the trend in the industrialized world since 1970 has been toward reduced energy intensity of economies. (On the other hand, total energy consumption is projected to rise in the next 25 years, with petroleum products leading the way.) Of the energy input of 20 million bbl/d of petroleum products supplied in the U.S. in 2001, 13 million bbl/d were used by transportation, specifically 8 million by light vehicles. By 2020, according to the EIA, transport is projected to account for 55 percent of the world's oil demand of about 119 million bbl/d. Thus improvements in transportation energy efficiency appear to have considerable potential for restraining oil demand. (Industrial use of petroleum products in the U.S. was only about 4.6 million bbl/d, so the opportunities for efficiency savings are less there.)

The EIA projects that advanced technologies and materials will keep new vehicle fuel economy from declining, but that this trend may be offset by a 27 percent increase in average horsepower for new cars from 2001 to 2025 (AEO 2003, p. 61). Applicable technologies include lighter weight materials, variable valve timing, direct fuel injection, and electric hybrid vehicles.

Residential, commercial, and industrial energy natural gas consumption also holds some opportunities for increased efficiency: more efficiently designed and controlled building energy systems, solid-state lighting, improved industrial processes. A major barrier to improved efficiency has been the cost/payback ratio. Without rate structures that reflect the externalized costs of energy, consumers have little incentive to reduce energy use. Energy savings frequently do not exceed conversion costs, making conversion uneconomic.

Alternatives to Oil[5]

Demand for oil might also be reduced if other sources of energy could substitute for it. Note that if the goal is to reduce the use of oil, and the solutions are not constrained by the objective of reducing GHG emissions, then coal and natural gas can continue as major energy sources. If attempting to reduce the threat of global warming by stabilizing atmospheric GHG is also a goal, then those two sources become more problematic.

Hydrogen appears to be the current favorite to substitute for petroleum in transportation. The Bush Administration proposes to use hydrogen to reduce U.S. oil demand by 11 million bbl/d by 2040.[6] (Note, however, that the EIA projects that, without moving to a hydrogen economy, by 2025 the U.S. will be using 29 million bbl/d, and importing 19.7 million of that.) Since hydrogen is an energy carrier rather than a primary fuel, energy must be used to produce hydrogen. Hydrogen production is not 100% energy-efficient, so more energy goes into producing it than comes out of using it. (Note, however, that if efficient end-use devices, such as fuel cells, consume the hydrogen, then some of the energy loss is mitigated.) If fossil fuels are used in production and if reduced CO_2 emissions is a goal, then carbon sequestration will also be necessary.

Conversion to a hydrogen economy from an oil economy might introduce other supply disruption vulnerabilities. If natural gas were used to generate the hydrogen, additional liquid natural gas might have to be imported from regions from which we now obtain from. If nuclear power is used, then fuel cycle technologies that reduced reliance on imported uranium might be advisable.

Coal

The DOE Hydrogen from Coal Program is researching ways to produce hydrogen from gasified coal. The research is directed towards doing so at affordable costs and towards finding ways to sequester the carbon.

Renewable Sources

Biomass, solar thermal and photovoltaic, wind, hydropower, ocean thermal, and tidal technologies might produce electricity that could in turn generate hydrogen to replace petroleum. Renewables to replace the current electric power generation system would require large changes in the electric power infrastructure. Hydrogen might also be generated directly from biomass or from solar thermal power plants. Hydrogen can be generated when energy (e.g. sun or wind) is available, and stored for later use. However, the cost and scale of deployment required make renewables seem unlikely candidate for producing the bulk of the hydrogen needed for a hydrogen economy.

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[5] Martin I. Hoffert et. al., "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet " (*Science*, Vol. 298, 1 November 2002); "Letters (Vol. 300, 25 April 2003)

[6] http://www.whitehouse.gov/news/releases/2003/02/20030206-12.html

Adding renewables to the electric power grid might also reduce the need for other energy sources. Today the worldwide trend is away from oil as a primary fuel for electricity: most new U.S. power plants are fueled with natural gas. Natural gas is relatively easy to store, and natural gas plants can adjust to demand loads more easily than coal or nuclear plants. That makes them complementary to renewable energy plants, some of which use intermittent sources of energy such as wind. If renewable energy plants could displace demand for electricity generated by natural gas, the gas could become available as transportation fuel. Often, however, renewable energy sources are not located near major load centers, so major transmission capacity investments would be needed to add such plants to the electric grid.

Nuclear Fission

As with renewables, nuclear fission to generate electric power could be an add-on to the existing power infrastructure and could be more or less dedicated to hydrogen production, either by direct thermo-chemical processes or by electrolysis. Expansion of nuclear power production would have to meet several criteria: acceptable safety, acceptable waste disposal, convincing nuclear weapon proliferation resistance, adequate long-term fuel supply, and affordability. With no new nuclear plants having been built for many years in the U.S., much of the design, construction, and manufacturing infrastructure has dissipated. Therefore, it will take time to design, license, manufacture, and construct new plants. As with renewables, producing large quantities of hydrogen from nuclear power plants will not happen in the near or medium term.

Nuclear Fusion

While in the very long term fusion appears to be an attractive power source, workshop participants noted that workable fusion power always seems to be 50 years away.

Methane Hydrates

Another alternative energy source being investigated is methane hydrates deposits. The feasibility and affordability of extracting this methane remains to be demonstrated.

Observations on Oil Supply Disruption Solutions

Oil dependence is a worldwide issue. Even if the U. S. were to substantially reduce the oil intensity of its economy, the economic risks to the U.S. of world oil supply disruptions would still be large unless its direct and indirect trading partners also reduced their vulnerabilities. Those working on technical solutions need to consider both industrialized and developing countries.

Given the current and projected dependence of the U.S.'s and the world's economies on oil, full oil independence does not appear technically or economically feasible in the next 20-40 years. Therefore, the question becomes one of estimating the amount of oil disruption risk reduction the various measures above can purchase, and at what price. Then, the most cost-effective *package* of measures might be identified.

Determining the appropriate level of effort to invest in reducing the risk is greatly complicated by the uncertainties in long-range estimates of the probabilities of the potential threats actually materializing.

Global Climate Change

Context

The Intergovernmental Panel on Climate Change (IPCC) has conducted simulations that predict "…a globally-averaged surface temperature increase by the end of the century of 1.4 to 5.8°C (2.5 to 10.4°F) relative to 1990." (See **Box 1**.) According to a committee of the National Research Council, the scientific community generally thinks that warming observed in the last 50 years is likely to have been due, at least in part, to the human-caused increase in levels of "greenhouse gases" (GHG), particularly carbon dioxide, in the atmosphere, although "…uncertainty remains because of (1) the level of natural variability inherent in the climate system on time scales of decades to centuries, (2) the questionable ability of models to accurately simulate natural variability on those long time scales, and (3) the degree of confidence that can be placed on reconstructions of global mean temperature over the past millennium based on proxy evidence."[7]

Box 1: Climate Change Simulations

Climate change simulations for the period of 1990 to 2100 based on the IPCC emissions scenarios yield a globally-averaged surface temperature increase by the end of the century of 1.4 to 5.8°C (2.5 to 10.4°F) relative to 1990. The wide range of uncertainty in these estimates reflects both the different assumptions about future concentrations of greenhouse gases and aerosols in the various scenarios considered by the IPCC and the differing climate sensitivities of the various climate models used in the simulations. The range of climate sensitivities implied by these predictions is generally consistent with previously reported values.

The predicted warming is larger over higher latitudes than over low latitudes, especially during winter and spring, and larger over land than over sea. Rainfall rates and the frequency of heavy precipitation events are predicted to increase, particularly over the higher latitudes. Higher evaporation rates would accelerate the drying of soils following rain events, resulting in lower relative humidities and higher daytime temperatures, especially during the warm season. The likelihood that this effect could prove important is greatest in semi-arid regions, such as the U.S. Great Plains. These predictions in the IPCC report are consistent with current understanding of the processes that control local climate.

Source: Committee on the Science of Climate Change, National Research Council, "Summary," *Climate Change Science: An Analysis of Some Key Questions* (Washington: National Academy Press, 2001

[7] Committee on the Science of Climate Change, National Research Council, "Summary," *Climate Change Science: An Analysis of Some Key Questions* (Washington: National Academy Press, 2001.

The models used by the IPCC suggested a gradual warming over the course of the next century. Moreover, since even the most intensive efforts to curb GHG emissions will not be able to stabilize atmospheric concentrations for some time, some additional warming is inevitable if those concentrations are indeed the major cause.

The paleoclimatic record, however, shows that, in the past, dramatic climate changes have occurred very abruptly (over years, not just over decades), as well.[8] Obviously these changes did not result from human-generated GHG. Therefore, it is quite possible they may occur again, whatever the future effect of the gases turns out to be. However, there is some concern that the warming induced by GHG might accelerate other processes and thereby increase the likelihood of more abrupt changes (see **Box** 2).

Box 2: Abrupt Climate Change

Recent scientific evidence shows that major and widespread climate changes have occurred with startling speed. For example, roughly half the north Atlantic warming since the last ice age was achieved in only a decade, and it was accompanied by significant climatic changes across most of the globe. Similar events, including local warmings as large as 16°C, occurred repeatedly during the slide into and climb out of the last ice age. Human civilizations arose after those extreme, global ice-age climate jumps. Severe droughts and other regional climate events during the current warm period have shown similar tendencies of abrupt onset and great persistence, often with adverse effects on societies.

Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events. The abrupt changes of the past are not fully explained yet, and climate models typically underestimate the size, speed, and extent of those changes. Hence, future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected.

Source: Committee on Abrupt Climate Change, National Research Council, *Abrupt Climate Change: Inevitable Surprises* (Washington: National Academy Press, 2001). http://books.nap.edu/books/0309075742/html/.

Threats, Risks, Uncertainties

Despite uncertainties about timing, intensity, and causes, further global warming appears likely as the 21st century unfolds. Potential negative effects of climate change include more hot weather, droughts, severe storms, and floods; increased ranges for tropical diseases; a rising sea level; and displaced agriculture. (These effects will vary in region, timing, intensity, abruptness, and the results of human mitigation efforts.) In one alarming scenario, disruption of the thermohaline circulation in the Atlantic Ocean would actually bring a much *colder* climate to Northern Europe, with severe consequences for the countries there.

The human consequences of these climate change effects might include increased migration (either within or across nations), competition for scarce water resources,

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[8] Committee on Abrupt Climate Change, National Research Council, *Abrupt Climate Change: Inevitable Surprises* (Washington: National Academy Press, 2001). http://books.nap.edu/books/0309075742/html/.

exacerbated border disputes, and inhibited economic development. In addition, climate change effects may reinforce other stressing trends already in evidence: demography (aging populations in industrialized countries, youth "bulge" in developing countries, food demands of growing numbers of people), water shortages, emerging and re-emerging infectious diseases, and economic inequalities. And, while nations may be expected to undertake adaptations to climate change consequences, resources used to adapt may be diverted from other important tasks. Finally, an indirect consequence of climate change might be a worldwide effort to mitigate greenhouse gas emissions by reducing fossil fuel consumption.

The various human consequences may in turn affect national and international security, as those terms are more traditionally understood. Such implications might include, for example: "failed" states or civil unrest leading to regional instabilities and feeding terrorist and criminal recruitment pools; interstate water or border conflicts; growing needs for disaster and famine relief; needs for international "adaptation assistance" in addition to development assistance; international political disputes over greenhouse gas mitigation responsibilities; reduction of resources available for national and international security activities (military or economic); or worldwide politico-economic changes resulting from decreased oil dependence.

It should also be noted that several of the problems cited above *already* exist in many developing countries: climate change may well exacerbate those problems and make economic and social progress even more difficult.

Solution Options

IPCC studies have addressed two broad kinds of responses to the threat of climate change: mitigation and adaptation. "Mitigation" refers to measures to stabilize the concentration of greenhouses gases, especially CO_2 in the atmosphere.[9] Climate models indicate that stabilization at different GHG levels will correlate with different degrees of global warming. "Adaptation" refers to measures taken to anticipate and to cope with the negative consequences of climate change. The attention of the workshop focused on possible mitigation measures, but some adaptation measures were mentioned.

Most mitigation interest centers on reducing the CO_2 emissions from the combustion of fossil fuels (which, for example, in the U.S. accounts for 98% of emissions).[10]

Efficiency

Since most energy is produced by burning fossil fuels, simply using less energy is one way to reduce CO_2 emissions. (See the discussion of efficiency above, under the subject of solutions addressing the oil dependency problem.)

[9] Other gases than CO_2, particularly methane, are also significant, but $CO_{2\ dominates}$.
[10] See ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057301.pdf, p. 19.

Carbon Sequestration

Another approach under research is to capture CO_2 before, during, or after fossil combustion, then to store it permanently, for example in geologic formations or in biological sinks.[11] Generally this could be done in the course of electric power generation, though capturing the gas generated by industrial processes might also be possible. Given the very large supplies of coal in the world, especially in the U.S. and in China, carbon sequestration might offer some nations a way to keep using relatively inexpensive, non-imported fossil fuels without increasing atmospheric CO_2. Workshop participants pointed out that, assuming the technologies were available, it would take 25-100 years to replace the worldwide power-generating infrastructure. Major issues for implementation would include: the need for legislative mandates, financial costs, energy costs of sequestration processes, and the nature of the CO_2 emission-rights market, if any.

Alternative Energy Sources

Most of the alternative fuel sources discussed above in the section on solutions addressing oil dependence also could reduce GHG emissions by reducing the burning of fossil fuels. However, if hydrogen as an energy carrier were generated by burning coal or natural gas without sequestering the CO_2, then fuel cells might address the oil problem while still contributing to the climate change problem.

Climate Engineering

Some have proposed, "…altering the planetary radiation balance to affect climate…[using]…technologies to compensate for the inadvertent global warming produced by fossil fuel CO_2 and other greenhouse gases."[12] Examples include injecting reflective dust or aerosols into the upper atmosphere or orbiting blocking objects in space. Engineering challenges look great and the risks of unforeseen consequences high.

Adaptation

Paleohistoric research suggests that global climate change happens, with or without human intervention. If CO_2 is the culprit this time, stabilization is unlikely to be achieved before at least some greenhouse warming occurs. Thus, for one reason or another at least some, and perhaps a great deal of, human adaptation to climate change will be necessary. Examples of adaptive measures mentioned were infrastructure changes (such as retreating cities from rising sea level or changing road engineering to adapt to loss of permafrost in northern regions), bioengineering agriculture to adapt to changed growing conditions, planned population migrations, and creating ocean habitats.

Insofar as the laboratory (and the nation) attempts to provide technology assistance for economic development, the need for developing countries to adapt to climate change impacts even as they try to advance economically could become a major part of the story.

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[11] See http://www.netl.doe.gov/coalpower/sequestration/

[12] Quotation and following examples from Hoffert, et. al., (footnote 5,), p. 986.

Observations on Climate Change Mitigation Solutions

- Like the oil dependence problem, the GHG problem is global. Limiting U.S. CO_2 emissions alone will not stabilize the world atmospheric concentration. Technological solutions will have to be appropriate to and accepted by a wide range of both industrialized and developing countries.

- There is a substantial, though not complete, overlap between solutions that would reduce oil dependence and those that would reduce GHG emissions.

- Given the potentially enormous displacement of fossil fuel energy that may be needed, no single solution is likely to be adequate. Research portfolio decision might therefore consider not only the risk and promise of each particular technology, but might also compare how different packages of technologies taken together could be expected to achieve the targeted levels of emission reduction.

Infrastructure Vulnerabilities

Context

In 2002 a committee of the National Research Council characterized U.S. reliance on its internal energy infrastructure as follows:

> Our economy and quality of life require a plentiful and continuous supply of energy. Though energy *per se* accounts for less than 10 percent of our gross national product, much of the balance of the economy will not function without it. Commerce, manufacturing, and employment are all highly dependent on natural gas, refined oil products, and electricity. Health care, schools, and universities are dependent on electricity and, frequently, natural gas. Telecommunications and information technology require a high-quality and reliable electrical power supply. Transportation is most dependent on oil products but also has great need for electricity to manufacture the vehicles and operate airports, traffic management systems, rail transit systems, and terminals. Because our reliance on energy is so great, our vulnerability to an interruption in its supply also is great.[13]

The energy infrastructure system includes extensive networks of electric generating facilities and transmission lines, natural gas pipelines, oil refineries and pipelines, coalmines, and transport. Electrical systems are vulnerable to physical or to cyber- or electromagnetic attacks on production or transmission equipment or on electronic control components. Natural gas system vulnerabilities include 275,000 miles

[13] Committee on Science and Technology for Countering Terrorism, National Research Council, "Chapter 6: Energy Systems" [excerpt], *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (Washington, DC: The National Academies Press, 2002 (http://www.nap.edu/html/stct/index.html

of transmission pipelines (including offshore), pipeline interconnections, compressor stations, “city gates,” liquefied natural gas facilities, and control systems. The most vulnerable components of the oil industry infrastructure are its refineries and pipeline pumping stations. Oil and gas industries would also be vulnerable to disruptions caused by the loss of electricity and water supplies needed to run the pipelines and refineries.

Threats, Risks, Uncertainties

The workshop identified several kinds of potential attacks on the energy infrastructure. A cyber-attack on supervisory control and data acquisition (SCADA) systems might seriously disrupt the oil or gas infrastructure systems. An explosion might take out a central point in an electrical power grid, disrupting food, water, and commercial computing systems. Smaller attacks might cause less extensive disruptions, but also might go on for weeks or even months before being detected or stopped.

Since so much U.S. electrical power is gas-generated, a successful attack on the gas infrastructure would also disrupt electricity supplies. Attacks on gas pipelines or facilities might also be attractive to terrorists because of the high visibility of explosions and fires. Increasing the danger is the fact that many gas pipelines run through the middle of towns and cities. Ports for importing liquid natural gas may offer additional opportunities for catastrophic attacks. The gas infrastructure also has the extra vulnerability that comes with a highly hierarchical network configuration.

Other possible threats include:

- vehicle attack on an energy facility (e.g., aircraft on nuclear power plant);
- explosive attack on a tanker or offshore platform (adds environmental threat);
- weapon of mass destruction at an energy port facility;
- destruction or damage to a hydroelectric dam that affects electricity, agriculture, environment, recreation, and public fears; and
- attack on an energy transportation system that either seriously disrupts distribution or creates fear about a sector (e.g. propane truck used in terrorist attack).

In workshop discussions, the issue of public perceptions and fears arose more than once. Similarly to the way the 9/11 attacks shut down U.S. air transportation, a high visibility attack on a nuclear power plant, or perhaps an attack on a refinery that released toxic chemicals, or a nuclear attack on a single port, might lead to economically damaging precautionary shutdowns.

The business practices, regulatory environment, and economics of the energy industries have inadvertently increased the vulnerabilities of the energy infrastructure both to natural disasters and to terrorist attacks.[14] Many gas pipelines are aging or obsolescent. Power plants lack fuel-switching capabilities, so that, for example, coal cannot be substituted for disrupted natural gas supplies. Paradoxically, as the system becomes economically more efficient, it becomes more brittle—there is less redundancy and reserve capacity with which to recover from damage.

The energy infrastructure as a system has lost integrity. No individual organization has full responsibility for its maintenance and reliability. Increasing system integrity would involve huge capital costs, but there is no long-term profit incentive to do so. With the deregulation of energy industries, owners lack the means to recoup the costs of infrastructure improvements. With a market, rather than national, focus on energy, there is little interest in energy security. In the absence of actual dramatic attacks, it is difficult to persuade taxpayers that the public should pay for infrastructure security improvements. As long as things seem to be going well, owners, managers, and public officials find complacency the path of least resistance.

Although the U.S. energy infrastructure appears vulnerable in many ways, it is difficult to quantify the risks. It is impossible to predict whether, when, or how often the kinds of attacks listed above might occur. The actual consequences of an attack could be very severe, or could be relatively minor. Terrorists might go after a catastrophic, or at least very dramatic event, or they might execute a sustained series of small attacks that undermine confidence in an energy system infrastructure.

Solution Options

Options for reducing the vulnerability of the domestic energy infrastructure include:

- Reduce the energy intensity of the economy;
- Diversify energy sources and applications;
- Move to more distributed power generation and transmission systems;
- Devise energy storage technologies and load-leveling technologies to enhance system resilience;
- Build self-healing infrastructure elements;
- Establish a national regulatory framework that emphasizes system integrity and security; and
- Encourage utility officials to analyze their system vulnerabilities and interdependencies, and prepare for possible attacks.

[14] On August 14, 2003, a power outage affecting some 50,000,000 in the northeast and upper midwest U.S. and southeast Canada appeared to confirm this assessment.

Reducing Energy Intensity

The efficiency measures discussed in the above sections on oil dependency and GHG reduction might decrease economic vulnerability to energy infrastructure disruptions. In transportation, for example, hybrid vehicles might reduce the impact of interruptions of gasoline refining and distribution. Or, if sectors of the economy could be made less transportation-dependent, that would in turn make them less energy dependent.

Diversifying Sources

An electric power system whose various generating plants used coal, oil, natural gas, and nuclear fission would be less vulnerable to disruptions of any given fuel source than one whose plants all used the same fuel. Similarly, a single power plant that could convert easily from one type of fuel to another would be more resilient to shortages of a given type. (Bear in mind that there are costs to be paid for either kind of diversity). A national motor vehicle fleet that ran on a variety of fuels—e.g., gasoline, natural gas, and hydrogen—would be more resilient as a whole than one relying only on gasoline and diesel oil, as is the case today. (But shutting down a major fraction of the vehicles normally in use would still be economically damaging.)

Distributing Power Generation and Transmission

The national electric power grid began as separate, small systems serving cities and industrial sites and evolved into a large, centralized, highly interconnected system. On the one hand, a highly interconnected system provides access to multiple supply sources; on the other hand, such a system is much more vulnerable to high-impact attacks on critical nodes. Decentralizing today's very large power plants into smaller, distributed plants would make both the generation system and the transmission system less vulnerable to single-point failures. (Smaller regions, numbers of people, and fractions of economic production would be affected.) However, the large-scale systems (such as the natural gas infrastructure) supplying primary energy to the power plants would still have to be protected.

Enhancing Grid Resilience

The ability to store electric power during off-peak-load periods would make it easier for the system to respond to unforeseen outages. Across the grid, more efficient load-leveling control technology could also add resilience. When disruptions occurred, power could be sent where needed without threatening further imbalances in the distribution system. In addition, affected regions would be less vulnerable to price spikes caused by temporary local disruptions of fuel supply.

Self-Healing Infrastructure Elements

It might be possible to build gas pipelines that could anticipate and repair erosion. Automated electrical grid control systems could reroute electricity in response to emergencies. These responses could be enabled by distributed sensors and electronic agents for rapid detection of problems and adaptive reconfiguration of networks.[15] The communications and control systems for the various infrastructure sectors could themselves be designed to recover from attack and disruption, whether cyber- or physical. Simulation models can be developed for understanding system vulnerabilities and self-healing techniques.

Regulatory Framework for System Integrity

The U.S. energy infrastructure has evolved over many decades into a highly interdependent, but not well integrated system. The impact of deregulation has sometimes been to provide no economic incentives for investments in restructuring for robustness or in taking precautions against attack. Attempting to establish such incentives by regulation would, of course, raise questions of how the public and private sectors should share the costs.

Education and Information for Utilities Officials

A greater awareness by those allocating industry resources of the potential threats to their businesses might increase their willingness to analyze their system vulnerabilities and interdependencies and to prepare for possible attacks, whether isolated or coordinated. System vulnerability analyses and red team exercises might help them decide how to allocate their security resources toward such actions as pre-positioning spare equipment and identifying skills and manpower that would be needed for emergency responses.

Observations on Infrastructure Vulnerabilities

- As with the other threats discussed in this workshop, it is easier to identify potential vulnerabilities than it is to arrive at plausible quantitative assessments of the probabilities of various threats. This makes it difficult to establish the "right" level of precautionary investments to make.

- Because the energy infrastructure is vulnerable not just to terrorist attack, but also to accidents and acts of nature, and because the system interdependencies can greatly amplify the potential losses to the economy, there is an argument for national-level attention to increasing system robustness and resiliency.

The Scope of the Problems

The workshop participants found it particularly difficult to assess the probabilities of the various consequences of the threats identified. That difficulty, in turn makes it very difficult to decide how to allocate resources (including research and development

[15] See, e.g., Massoud Amin, "Toward Self-Healing Energy Infrastructure Systems," *IEEE Computer Applications in Power,* 2001, at http://rodin.wustl.edu/~massoud/Amin_IEEE-CAP.pdf.

resources) to measures intended to address the threats. In a report chapter on "Decision-Making Frameworks," [16] a working group of the IPCC identified several characteristics of the problem of climate change, some of which are unique to that problem, but most of which in fact apply to all three of the major problem areas discussed in this workshop. **Table 1**, adapted in part from the IPCC study, addresses those characteristics and several others.

Table 1: Really Hard Problems

Obstacles to Analysis and Solution Decisions	***Oil Dependence***	***Climate Change***	***Infrastructure Vulnerability***
Global scope	World economy is oil dependent; U.S. (e.g.) solutions alone insufficient;	Human contributions (though debated) appear global, as are consequences (however change is caused); joint solutions more effective than separate actions	Problem centers on U.S.-Canada-Mexico, though import facilities connect it to foreign threats.
Public Goods and Market Externalities	Social costs not internalized to the oil market (e.g. security, environmental costs of oil dependence); monetary costs of remedial measures known better than intangible future benefits.	Markets do not account for possible eventual costs of GHG emissions; monetary costs of remedial measures known better than intangible future benefits.	Markets do not provide incentives for enhancing infrastructure security; monetary costs of remedial measures known better than intangible future benefits.
Intergenerational transfers of costs and consequences	Significant reductions of oil dependence would take decades preceded by substantial public investments; costs accrue early, benefits later.	If atmospheric GHG concentrations are reduced (and this mitigates climate change), current generation will pay for benefits to later generations (or else later generations will pay for current energy consumption patterns)	Infrastructure resiliency improvements need not take a full generation, though substantial restructuring would.

[16] *Climate Change 2001: Mitigation - Contribution of Working Group III to the Third Assessment Report of IPCC* (IPCC. 2001), Chapter 10, see lhttp://www.grida.no/climate/ipcc_tar/wg3/pdf/10.pdf

Multiple decision-makers	Both within and across nations, consumers, industry, governments, and international organizations make consequential choices.	Same as for oil dependence.	Consumers, industry, local, state, federal, governments, as well as some foreign countries make consequential choices.
Heterogeneous contributions and consequences	Different oil consuming nations have different consumption and import patterns and oil intensity trends; disruption threats among suppliers vary.	Carbon and other GHG emissions vary internationally; projected consequences and abilities to adapt vary.	Vulnerabilities vary across energy types. Event consequences may be local, regional, or national.
Significant Policy Interactions	Measures taken to solve one problem may worsen (or ameliorate) another problem: e.g., lowering U.S. oil use alone may increase global oil dependence by reducing oil prices.	E.g., economic growth and reduction of poverty can increase GHG emissions.	Policies to control consumer costs, protect the environment, tax and subsidize industry, and maintain reliable service all interact.
Pervasive Uncertainties	No way of predicting whether potential security threats to oil imports will materialize.	Climate models cannot specify probability, timing, extent of climate changes and role of GHG; human actions and reactions also unpredictable.	No way of predicting whether potential security threats will materialize.
Inertia	Security threats are near- and long-term, but possibility of oil independence is only long-term.	Cumulative nature of CO_2 concentrations makes early stabilization impossible. Current energy (GHG emitting) infrastructure only slowly replaceable.	Physical plant of domestic energy infrastructure will only turn over in decades; low public-political perception of need for change.

Human behavior is central to the obstacles listed. As the workshop came to a conclusion, several participants noted the importance of understanding the psychological, social, and economic dimensions of the problems if effective technical solutions are to be devised and implemented. And throughout the discussions, examples of the importance of the human dimension emerged. Some examples follow.

Threat Complacency. In the absence of dramatic events or very stark threats, people (both the general public and decision makers) seem to be complacent about some serious risks—such as those stemming from energy infrastructure vulnerabilities.

Crisis Reactions. On the one hand, people (and politicians) may overreact to dramatic events—e.g., shutting down an entire industry because of a single serious accident or attack. On the other hand, it seems to take an atmosphere of crisis to stimulate action to address some large-scale problems (like oil dependence). Although it might then be argued that some crises are beneficial for that reason, the downside is that frequently, after the immediate crisis passes, attention and resources turn to some other problem and complacency resumes. The on-and-off history of the U.S. pursuit of "energy independence" over the past three decades illustrates this point.

Political System Emphasizes the Short Term. In many cases the political system seems unable to address large, long-term problems. Election cycles, changes of administration, and voter behavior do not reward continuity and long-term investment.

Fragmentation of Political Power. The fragmentation of power among localities, states, and the federal government, fragmentation of jurisdiction among agencies of the federal government, and perhaps even the constitutional legislative-administrative separation make it difficult to devise and implement integrated solutions to large-scale problems.

Resistance to Change. Solutions that appear rational from a technical point of view sometimes meet resistance for psychological, social, or cultural reasons. Some cite as an example the unwillingness of consumers to adopt energy conservation and efficiency measures, even as they agree that in principle these would be good things to do. Related is the "not-invented-here" syndrome, in which people resist adopting technologies that seem, in one sense or another, to be foreign, unfamiliar, or imposed from without. In the case of technology transfers from one nation to another, the problem is complicated by socio-cultural differences that may not be apparent to those offering the technology.

National Sovereignty. While nation-states persist, international relations will remain the major arena in which global solutions to global problems will have to be devised and implemented. Nations may perceive problems differently, be more or less willing to cooperate in international organizations and arrangements, or be more or less willing to accept leadership from those (such as the U.S.) attempting to offer it.

Conclusion: Some Issues for Sandia

Each of the three subjects discussed at this workshop has significant U.S. national security implications. Each has substantial technology components. Each appears a legitimate area of concern for a national security laboratory with relevant technology capabilities. Sandia National Laboratories will not define or determine national policy in any of these areas, but it may be able to:

- work on framing the problems so as to enhance national understanding of the issues and potential solutions;

- develop more complete understanding of the implications of proposed technologies and policies for one another; and

- pursue a portfolio of energy-related research that can widen and strengthen the options available to current and future national policy makers.

The technology research portfolio might be allocated in various proportions to one or more of the following objectives:

a. mitigate risks of disruptions of U.S. oil imports;

b. mitigate risks of disruptions of worldwide oil imports;

c. reduce the contributions of U.S. energy consumption to GHG concentrations;

d. reduce the contributions of worldwide energy consumption to GHG concentrations;

e. ameliorate climate change impacts on energy and water infrastructures;

f. reduce vulnerability of domestic energy infrastructure; or

g. reduce the vulnerability of globally important energy infrastructure.

Any of these objectives might be pursed independently of the others, and the technologies pursued, if deployed, might either positively or negatively affect achievement of the other objectives. Alternatively, the technologies might be chosen for research and development in part because of their potential to advance multiple objectives simultaneously. For example, alternative energy sources might be developed in ways that make them applicable in other oil-dependent countries, and not just in the U.S. economy. Energy sources that not only replace imported oil, but also reduce GHG emissions, could address all of the first four objectives. Some of these energy sources might also be deployed in distributed configurations—thus contributing to domestic infrastructure resilience as well.

Whatever the mix of technology research pursued, workshop participants suggested two broad principles that they thought should inform the work:

1. Understand the human dimensions, and

2. Think globally.

Understand the Human Dimensions

For the laboratory to play a meaningful role in contributing to solutions to national problems such as these, it needs to understand the political, economic, and social environments in which it expects its work to be accepted and used. This generalization applies on several levels. At a higher level, understanding the societal environment should help in selecting technology solutions for research that have a better chance of seeming to policy makers to be the right answer at the right time. At a somewhat more tactical level, it is important to present technologies to potential customers (whether they be government agencies, legislators, or the public) in ways that address their needs as they perceive them. At the implementation level, technologies are adopted and used by human beings, and must be designed and developed taking account of the real world in which they are supposed to function.

The human dimension takes on added importance and complexity when the problems and solutions are international. Technologies to be transferred to developing countries need to be, in many cases, adaptable and affordable in the societies for which they are intended. Solutions proposed for multinational adoption need to take into account both diverse perceptions of the problem being addressed and differences in the cultures and economies expected to adopt them.

Think Globally

As one workshop participant put it, the laboratory would do well to have a hierarchical perspective on the problems it chooses to address: from the globe to the nation to Sandia. (The “Waging Peace” theme takes this perspective.) The energy infrastructure vulnerability problem will not be solved at Sandia, but the laboratory might make significant contributions to the solution if it understands the relative roles of the laboratory, the other national laboratories, the government, and industry. Although the infrastructure problem is largely national (with some international components), the problems of oil dependency and climate change are not amenable to solution by the policies of any one nation—even the one that is currently the largest single energy consumer. Therefore, views, concerns, policies, and plans of other countries will do much to determine which solutions might work and which might not.

Appendix I: Summaries of Pre-Fest Readings

Contents

Background Data

1. Energy Information Administration, U.S. Department of Energy, "Overview," *Annual Energy Outlook 2003*, excerpt.

2. International Energy Agency, "Executive Summary," *World Energy Outlook 2002*.

3. National Energy Policy Development Group, "Overview," *Reliable, Affordable, and Environmentally Sound Energy for America's Future* (Washington, GPO, 2001), excerpt.

4. James M. Kendell, "Measures of Oil Import Dependence," Energy Information Administration (http://tonto.eia.doe.gov/FTPROOT/forecasting/060798.pdf).

5. Committee on the Science of Climate Change, National Research Council, "Summary," *Climate Change Science: An Analysis of Some Key Questions* (Washington: National Academy Press, 2001)

Oil Dependence

6. Michael A. Toman, "International Oil Security: Problems and Policies," *The Brookings Review*, Spring 2002 Vol. 20 No. 2.

National Security Implications

7. Center for Strategic and International Studies, "Executive Summary," *The Geopolitics of Energy into the 21st Century: The Report of the CSIS Strategic Energy Initiative* (2000) http://www.csis.org/sei/geopoliticsexecsum.pdf

8. Amory Lovins, excerpt from "Out of the Oil Box: A Roadmap for U.S. Mobilization" (undated ms.)

9. Anthony H. Cordesman, Summary, "The US and the Middle East: Energy Dependence, Demographics, and the Myth of Oil Wealth" (Washington: Center for Strategic and International Studies, Dec. 26, 2002)

10. Robert Baer, "The Fall of the House of Saud," *The Atlantic Monthly*, May 2003, pp. 53

Energy Infrastructure

11. Committee on Science and Technology for Countering Terrorism, National Research Council, "Chapter 6: Energy Systems" [excerpt], *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (Washington, DC: The National Academies Press, 2002

12. Douglas M. Chapin, et. al., "Nuclear Power Plants and Their Fuel as Terrorist Targets," *Science*, vol. 297, 20 September 2002, pp. 1997-1998; "Letters: Revisiting Nuclear Power Plant Safety," *Science*, vol. 299, 20 January 2003, pp. 201-203; and Edwin S. Lyman, "Statement on the *Science* [article]," Nuclear Control Institute press release, September 20,20002.

Solutions

13. Martin I. Hoffert et.al., "Advanced Technology Paths to Global Climate Stability: Energy for a Greeenhouse Planet " (*Science*, Vol. 298, 1 November 2002)

14. Secretariat to Standing Group on Long-Term Cooperation International Energy Agency, "Moving to a Hydrogen Economy: Dreams and Realities," IEA/SLT(2003)5, 3 Jan 2003.

1. Energy Information Administration, U.S. Department of Energy, "Overview," *Annual Energy Outlook 2003,* excerpt.

- Energy prices extremely volatile in 2002
- Spot natural gas up from $2 to $3-4/thousand cubic feet
- Oil up from $16 to $25-30/barrel
- Availability of natural gas at competitive prices through 2025 a major consideration
- Net oil imports up from 37% in 1980, 42% in 1990 to 55% in 2001
- Previously expected downturn in nuclear capacity delayed or eliminated by improved plant performance and license extensions
- OPEC production to increase from 28.3 million barrels in 2001 to 60.1 in 2025, non-OPEC to increase from 45.5 to 58.8 million barrels MMB, OPEC market share grows from 38% to 55%.
- Natural gas share of electricity generation will increase from 17% to 29%; coal share will decline from 52% to 48% from 2001 to 2025; renewables will increase 2.5%/yr from 2001 to 2020.

Average Annual Growth Rates from 2001 to 2025 and Energy Demand (Quadrillion BTUs)

GDP	3%	$18,917B	Energy Intensity	-2.3%	7.36 BTU/$ GDP
Natural Gas	1.8%	35.8 Q	Residential	1%	24.5 Q
Coal	1.3%	29.4 Q	Commercial	1.6%	23.5 Q
Petroleum	1.7%	56.6 Q	Industrial	1.3%	40.4 Q
Renewables	1.6%	8.8 Q	Transportation	2%	40.4 Q
Electricity	1.8%	17.9 Q	CO_2	1.5%	2.1E9 Tonnes

2. International Energy Agency, "Executive Summary," *World Energy Outlook 2002*

Supply and Demand

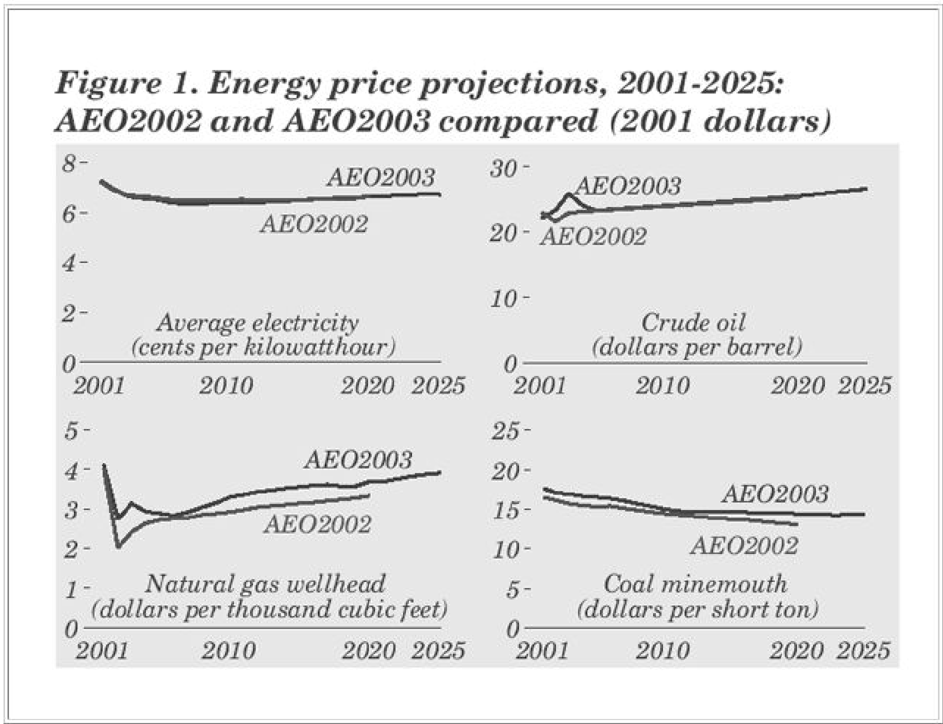
- Through 2030, fossil fuels will continue to dominate global energy use.
- Demand will rise fastest in developing countries.

- Transport uses of oil will outstrip all others.

- International energy trade, almost entirely in fossil fuels, will expand dramatically.

- The governments of importing countries "…will need to take a more proactive role in dealing with the energy security risks inherent in fossil-fuel trade. They will need to pay more attention to maintaining the security of international sea leans and pipelines. And they will look anew at ways of diversifying their fuels, as well as the geographic sources of those fuels.

Annual Energy Outlook 2003 With Projections to 2025



AEO2002 projections: Energy Information Administration, Annual Energy Outlook 2002, DOE/EIA-0383(2002) (Washington, DC, December 2001). AEO2003 projections: Table A1

Carbon Dioxide

- Rising demand will drive up carbon dioxide emissions, and the geographical sources of new emissions will shift drastically from the industrialized countries to the developing world.

- Even Kyoto protocol signers are unlikely to meet their emissions targets.

- Carbon sequestration and storage technologies are promising, but will be costly and unlikely to be deployed in large scale before 2030.

- An Alternative Policy scenario of energy savings and more efficient technologies could lead to reduced CO_2 emissions and reduced import dependence (gas 13% under Reference scenario and oil 10% under.

- Under present trends, the role of nuclear power will decline.

Poverty

- In 2030, 1.4 billion people, or 18% of population will still lack electricity. Lack of electricity exacerbates poverty and precludes industrial jobs.

- The share of people relying on biomass for cooking and heating is projected to decline, but the total number of people doing so will grow. Thus the development of more efficient biomass technologies is vital for alleviating poverty in rural areas.

3. National Energy Policy Development Group, "Overview," *Reliable, Affordable, and Environmentally Sound Energy for America's Future* (Washington, GPO, 2001), excerpt.

Five Specific National Goals

Modernize Conservation

- Direct federal agencies to conserve, especially during peak demand
- Increase funding for efficiency and renewable R&D that is cost-shared and performance based
- Create income tax credit for hybrid and fuel cell vehicles
- Extend Energy Star program
- Fund Intelligent Transportation Systems program, fuel-cell and clean buses
- Provide tax incentive, streamline permitting for Combined Heat and Power
- Direct DOT to review CAFE standards, considering NAS July 2001 study

Modernize Our Energy Infrastructure

- Direct agencies to improve pipeline safety and expedite permitting
- Direct federal agencies to expedite energy project permits on a national basis
- Grant authority to obtain rights of way for transmission lines, as already exists for natural gas pipelines and highways
- Enact legislation to encourage new generation, enhance reliability, promotes renewables
- Implement regulatory changes to improve electric reliability
- Expand research on transmission reliability and superconductivity

Increase energy supplies

- Open a small part of the Artic National Wildlife Refuge
- Earmark $1.2B of ANWR bid bonuses for renewable resources
- Expand tax incentives for landfill gas, wind, biomass, and biomass cofiring
- Provide $2B over ten years for clean coal
- Streamline hydropower relicensing
- Establish a nuclear waste repository and streamline power plant licensing

Accelerate Protection and Improvement of the Environment

- Enact multi-pollutant legislation providing flexible market-based caps
- Increase export of environmentally friendly, market-ready US technologies
- Earmark ANWR royalties to fund land conservation efforts
- Reduce truck idling emissions at truck stops

Increase Energy Security

- Increase funding for Low Income Energy Assistance Program when oil and gas prices are high

- Double funding for DOE’s Weatherization Assistance Program
- Direct FEMA to prepare for potential energy-related emergencies
- Support cross-border energy development with Mexico and Canada

4. James M. Kendell, "Measures of Oil Import Dependence," Energy Information Administration

- "Knowing that the Nation imports 2 percent or 50 percent of its oil tells how *dependent* it is, but not how *vulnerable* it is to oil price shocks and to oil supply disruptions."
- "Even as the world and the US have moved away from dependence on Persian Gulf oil…the reliance on large suppliers has increased.
- Strategic reserves can protect against disruptions, but the US reserve has declined from 115 days of supply in 1985 to 63 days (in 1998; 53 days in 2003).
- Surge capacity (reserve production capacity) in the world has also been declining.
- Oil import expenditures as a percentage of all import spending has continued to fall.
- The "oil intensity" of the US economy—barrels of oil consumed per day per million dollars of GDP—has also continued to fall.

5. Committee on the Science of Climate Change, National Research Council, "Summary," ***Climate Change Science: An Analysis of Some Key Questions*** **(Washington: National Academy Press, 2001)**

<u>Some conclusions on Climate Change:</u>

- Natural variability is large over large regions and short times (decades)
- Greenhouse gas emission is, on the whole increasing
- CH4 and CO2 are at their highest over past 400,000 years
- Most of the increase is human induced
- Non-uniform (vertical and horizontal) warming appears to be real
- Greenhouse cases probably are the cause
- Temperatures will probably increase, but projections are uncertain
- Feedbacks (clouds, snow packs) are a big uncertainty
- Water vapor feedback increases temperature
- Ice-albedo loss with water vapor increases forcing function by 2.5X
- Politics: IPCC report doesn't reflect uncertainties as well as it reflects concern associated with human induced climate change

6. Michael A. Toman, "International Oil Security: Problems and Policies," *The Brookings Review*, Spring 2002 Vol. 20 No. 2.

- "The key issue in global oil security is not "running out"—the world has hundreds of years of existing and potential reserves. Nor is it targeted embargoes or how much oil the United States buys from particular countries—both are meaningless in an integrated world oil market. The key issue is energy prices."

- Although OPEC has recently had difficulties, "In the longer term, OPEC could be in a stronger position to exercise substantial market power. It controls around three-quarters of the world's known oil reserves, and the U.S. Energy Information Administration projects that its share of world output could rise to 50 percent by 2020."

- "…the vulnerability of the U.S. economy to oil price shocks depends on the intensity of petroleum consumption here and throughout the industrialized world, not on total U.S. imports or imports from the Middle East.

- "…the economic cost of eliminating oil imports either by increasing domestic supplies or by reducing energy consumption would be enormous."

- "…it is misleading to attribute the costly U.S. presence in the Middle East solely to the nation's high degree of oil dependence and to argue that import reductions could significantly reduce the costs of Middle East involvement."

- "... increasing U.S. domestic petroleum output will do relatively little to enhance energy security."

- "…The key to increasing U.S. energy security, from a macroeconomic perspective, is reducing the petroleum intensity of economic activity."

- "While conservation and energy efficiency improvements can help enhance energy security, a more robust policy program would include other measures. In the shorter term, the government must figure out how to use the Strategic Petroleum Reserve more effectively."

- "We can get as much energy security as we are willing to pay for through a combination of higher current energy prices and increased R&D efforts. But we cannot get something for nothing, at the end of a drill bit or otherwise."

7. Center for Strategic and International Studies, "Executive Summary," ***The Geopolitics of Energy into the 21st Century: The Report of the CSIS Strategic Energy Initiative*** **http://www.csis.org/sei/geopoliticsexecsum.pdf**

Some key projections

- In the next 20 years, The Persian Gulf, led by Saudi Arabia, will remain the key marginal supplier of oil to the world market; it share of world production will increase while those of North America and Europe decline.
- The Russian share of world production will increase from 9% to 12%; Caspian oil will not be a pivotal part of world production.
- Asian dependency on Persian Gulf oil will rise significantly, and thus so will the oil at risk in international sea lanes.

Effects of geopolitics on energy

- By 2020, 50% of oil production will be in countries at high risk of political instability.
- In a globalized world economy, interdependence of energy producers and consumers will grow.
- NGOs will have greater impact on how energy is produced and consumed.
- Increasingly complex infrastructures will be vulnerable to terrorists and cyberterrorists.
- Armed conflict in energy producing regions may cause disruptions.

Effects of energy on geopolitics

- Economic recessions could trigger instability in exporting countries; or, growth in consumption could give exporters more power.
- Supply could be disrupted by inadequate investment in production capacity, political events, or logistical interruptions.
- Chinese efforts to secure enough energy could lead to conflicts or greater Chinese military ties to Persian Gulf exporters.
- Some international ties may be strengthened by energy infrastructure deals (e.g. China-Russia, EU Russia.
- Industrialized nation's strategies to reduce carbon emissions could lead to disputes with developing countries.

Some policy issues

- US economic sanctions against oil producing nations limit growth of production infrastructure that will be needed to meet future demand.

- Policies toward producer countries should encourage foreign investment in infrastructure.
- US will need to maintain military capabilities to protect US and allied access to energy and sea lanes.
- Governments should work with private section to reduce energy infrastructure vulnerabilities.
- Governments should pursue diversity of supplies and should maintain adequate strategic reserves against disruptions.
- Successful reduction of carbon emissions will require providing both themselves and developing nations with alternative technologies to meet growing energy demands.

8. Amory Lovins, excerpt from "Out of the Oil Box: A Roadmap for U.S. Mobilization" (undated ms.)

- U.S. payments for oil imports have paid for profligacy, polarizing inequities, weapons of mass destruction, state-sponsored violence, and terrorism.
- U.S. economy is vulnerability to oil prices rises, and would be even if it imported no oil.
- Domestic oil infrastructure is highly vulnerable to terrorist attack.
- Persian Gulf, especially Saudi, oil infrastructure is vulnerable to disruption.
- The true cost of oil includes $60 billion per year in readiness for military intervention in the Gulf, plus price of war(s) there.
- Environmental effects of oil production can degrade environments and thereby foment social unrest.
- Consequences of fossil-fuel induced climate change may especially harm poor and unstable country economies.
- Producer country economies suffer from unaccountable, unresponsive governments, undiversified economic systems, corruption, concentration of wealth, excessive military expenditures that all inhibit economic and political development.
- US relationships with these governments lead to criticisms of diplomatic double standards, perceptions that all policies are oil-driven
- Poor consumer country economies are constrained by oil debt
- Oil imports increase US trade imbalance abroad and impose opportunity costs in allocation of national resources.

9. Anthony H. Cordesman, Summary, “The US and the Middle East: Energy Dependence, Demographics, and the Myth of Oil Wealth” (Washington: Center for Strategic and International Studies, Dec. 26, 2002)

- Even if *all* the additional US production of oil and all other forms of energy called for in the Bush energy policy was actually achieved, it would have virtually no impact on US strategic dependence on oil imports.
- Many manufactured goods US imports themselves depend critically on oil imports.
- US also depends on other nations to buy our exports and invest here. “Our vital strategic interests depend on the global availability of oil at moderate prices, not on our own imports.
- Barring a technological miracle, global economic dependence on oil will continue for decades. Therefore, “We will still have to prepare for a major regional [military] contingency in the Middle East.

10. Robert Baer, "The Fall of the House of Saud," *The Atlantic Monthly*, May 2003, pp. 53-62.

- The Saudi production and transport infrastructure is vulnerable to commando attack or sabotage at several key points:
  - Abqaiq oil processing facility—6.8 mbbd could be reduced to 1
  - Ras Tanura and Ju'aymah loading terminals (4.5 mbbd and 4.3 mbbd)
  - Ras Tanura offshore Sea Island Platform #4 (2.25 mbbd)
  - Pump Station No. 1 from Abqaiq to Yanbu on Red Sea (0.9 mbbd)
  - Qatif Junction manifold complex for pipes from Abqaiq to loading terminals

- "The US and the rest of the industrialized world are absolutely dependent on Saudi Arabia's oil reserves and will be for decades to come."
- Terrorism or political revolution, shutting off spigot, would be devastating to US and global economy.
- "Saudi oil is controlled by an increasingly bankrupt, criminal, dysfunctional, and out-of-touch royal family that is hated by the people it rules and by the nations that surround the kingdom."
- US government looks the other way.
- US corporations hire Saudi "crooks and known financiers of terrorism" who land deals paying large commissions that further erode the Saudi budget alienate the ruling class from everyone else.
- "…sometime soon, one way or another, the House of Saud is coming down."

11. Committee on Science and Technology for Countering Terrorism, National Research Council, "Chapter 6: Energy Systems" [excerpt], *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (Washington, DC: The National Academies Press, 2002 (http://www.nap.edu/html/stct/index.html

- Energy systems include extensive networks of electric generating facilities and transmission lines, natural gas pipelines, oil refineries and pipelines, coal mines, and transport.
- "…the industry's response capabilities were not designed to handle extensive, well-organized acts of terrorism aimed at key elements of the energy system.
- Electrical systems are vulnerable to physical or to cyber- or electromagnetic attacks on production or transmission equipment or on electronic control components.
- The most insidious and harmful attack would exploit vulnerabilities of the power grid in ways that led to widespread and extended blackout, or even grid collapse.
- An attack on one nuclear power plant might led to a decision to shut down all, comprising 20% of US production.
- Natural gas system vulnerabilities include transmission pipelines (including offshore), pipeline interconnections, compressor stations, city gates, liquefied natural gas facilities, and control systems.
- The facilities are vulnerable to physical attack and the controls systems to cyber-attack.
- "Under present conditions, a well-planned and coordinated terrorist attack could take out the nation's gas transmission systems and keep key pipelines out of service for an extended period of time."
- The most vulnerable components of the oil industry infrastructure are its refineries and pipeline pumping stations.
- Many major refining process components are unique and could take months or years to replace. On the other hand most large refineries have several trains of similar units, so a highly coordinated attack would be needed to bring them down for a long time.
- A few refineries use highly toxic chemicals that an attack might release on the surrounding population.
- "A coordinated attack on several key pumping stations…could lead to serious economic disruption.
- Oil pipeline and refinery supervisory control and data acquisition (SCADA) systems "…are particularly vulnerable to disruptions because they were initially designed without consideration of security."
- The industry would also be vulnerable to disruptions caused by the loss of electricity and water supplies needed to run the pipelines and refineries.

12. **Douglas M. Chapin, et. al., "Nuclear Power Plants and Their Fuel as Terrorist Targets," *Science*, vol. 297, 20 September 2002, pp. 1997-1998; "Letters: Revisiting Nuclear Power Plant Safety," *Science*, vol. 299, 20 January 2003, pp. 201-203; and Edwin S. Lyman, "Statement on the *Science* [article]," Nuclear Control Institute press release, September 20,20002**.

Chapin et. al.:

- Spent nuclear fuel casks are "nearly indestructible," and even an anti-tank weapon could only scatter a few chunks of fuel on the ground; no harmful radiation risk at any significant distance.
- "No air plane, regardless of size" could fly through a nuclear reactor containment wall (SNL video of test cited).
- Three Mile Island shows even a meltdown would harm few if any.
- Chernobyl is not relevant because radiation was spread by burning graphite (not in US reactors) and most damage to people caused not by radiation, but by fear and poor planning.
- Radiation risks are overstated: "To tell people that they and the Earth are in mortal danger from events that cannot cause significant public harm is to play into the hands of terrorists by making a minor event a cause for life-endangering panic."

Letters:

Frank von Hippel:

- SNL has disputed relevance of its test
- NRC NUREG-1728 cites threat of fires in spent fuel pools (n.b.: NRC Commissioner McGaffigan repudiates this report: http://www.nrc.gov/reading-rm/doc-collections/commission/speeches/2003/s-03-012.html.
- Disproportionate public fears understandable because of "learned distrust" of reassurances from the industry."

David Brenner

- Spent fuel bombed or stolen for "dirty bomb" is a risk.
- Cancer risks may be low, but over large numbers are significant.
- Edwin Lyman (in letter and press release cited)
- Terrorists could exploit common-mode failure weaknesses to produce core damage.
- Terrorists seizing control could prevent operators from taking corrective actions.
- Only a small group of dissidents believes in a dose threshold for the carcinogenic effects of radiation.
- Aircraft damage to control room, spent fuel pool, and auxiliary building could cause severe radiological release.

Chapin et. al.:

- Commenters do not attempt to answer referenced reports showing no casualties from containment breaches

- Even in containment breaching scenarios, most radioactivity remains bound in the fuel
- Zirconium fires in spent fuel pools would not disperse radiation
- People can be evacuated, thyroid cancers can be treated
- Linear no-threshold assumptions about cancer dose rates are wrong according to National Council on Radiation Protection and Measurements report.
- Low dose rates are good for you.

13. **Martin I. Hoffert et.al., "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet " (*Science*, Vol. 298, 1 November 2002); "Letters (Vol. 300, 25 April 2003)**

- The Kyoto Protocol is too strong to persuade US to accept economic burdens and too weak to produce enough CO_2 reductions to achieve 550 ppm at 30TW of global energy production.
- "Arguably, the most effective way to reduce CO_2 emissions with economic growth and equity is to develop revolutionary changes in the technology of energy production."
- The IPCC's report is too optimistic about available technologies.
- Technology Candidates:
    - <u>Efficiency:</u> Has potential, but effects of plausible increases could be overwhelmed if China and India move to cars. Carbon neutral or CO_2 "air capture" may be best bet.
    - <u>Decarbonization :Hydrogen:</u> "Per unit of heat generated, more CO_2 is generated by making H_2 from fossil fuel than by burning the fossil fuel directly." Renewable- or nuclear-powered is not yet cost effective.
    - <u>Sequestration</u>*:* If feasible, carbon sequestration would be compatible with existing fossil fuel infrastructures. Could be valuable, but "if other emission-free primary power sources of 10-30 TW are unavailable by 2050, then required sequestration rates would be enormous.
    - Renewables: Include biomass, solar thermal and photovoltaic, wind, hydropower, ocean thermal, and tidal.
        - All suffer from low areal power densities.
        - Better photovoltaics and reengineered power grids might provide a new electricity model.
        - Space-based solar power might be feasible in second half of century if launch costs could be reduced.
    - <u>Nuclear Fission and Fusion:</u>
        - Passively safe reactors might provide emission-free electric power but pose problems of waste disposal and weapons proliferation.
        - "The main problem with fission…is fuel—there may not be enough U—breeders required.
        - Most promising is fusion, but it cannot be relied upon by mid-century.
    - <u>Geoengineering</u>: Various methods of blocking sunlight: *questionable and risky but worth researching.*

Letters

- Range of uncertainties for energy requirements by 2050 (20-50 TW) needs to be planned for.
- Doubtful that radically new technologies such as solar power satellites or fusion are feasible in necessary time frame. Ergo, focus first on feasible technologies to get started on stabilization.
- Nuclear technology is best candidate.
- Do not dismiss individual technologies in isolation but consider combined potential (including efficiency and renewables) plus economic and institutional changes.

Authors' response

- Existing technologies can contribute, but more will be needed.
- Fusion or solar power sats market penetration might be accelerated by government research
- Efficiency seems unlikely to match expected 2%/year growth in power demand.

14. Secretariat to Standing Group on Long-Term Cooperation International Energy Agency, "Moving to a Hydrogen Economy: Dreams and Realities," IEA/SLT(2003)5, 3 Jan 2003.

Some facts:

- Currently 98% of H_2 is made from hydrocarbons.
- Current 20 billion cubic meters (about 1.7 billion kg) of H_2 is made in the US per year, mostly for on-site chemical applications.

Some guesses:

- World electric power Generation capacity additions will be coal and Nat. Gas for next 30 years.
- CO_2 recapture and sequestration is possible when making H_2 from coal or gas.
- Electrolysis is too inefficient (expensive) for making H_2, but maybe solar thermal won't be.
- Methanol and Ethanol fuel cells might be desirable because of high well-to-wheel efficiencies, but require on board reformers. Methanol is also corrosive and very toxic to humans.

Some hurdles on the road to a Hydrogen Economy

- Thermal content of hydrogen per unit of mass is high (over 1 Therm per kg compared to about 0.4 Therms for 1 kg gasoline), but hydrogen requires enormous pressures to store and transport.
- H_2 production costs are high, and all economically reasonable production methods result in CO_2 production, requiring sequestration. Scale-up to quantities required for transportation fuel is probably very expensive.
- H_2 transportation and distribution will also be high compared to existing fossil fuels (perhaps as much as an order of magnitude) per unit of energy.
- H_2 storage in tanks on cars will require pressures of 700 bar (10,000 lbs/ sq. in) which consumes much energy (in filling) and results in only a few percent of the weight of the tank as fuel.
- Liquefied hydrogen storage requires much energy and boil off of about 1% per day.

Recommendations:

- Pursue fuel cell development (perhaps for stationary use) in parallel path with H_2 production technologies.

- Make investments in large-scale H_2 production technologies.
- Short term: H_2 from fossil fuels.
- Intermediate term: H_2 from hydropower, solar, wind and high temperature gas reforming using coal.
- Longer term: photobiological production of H_2.

Appendix II: Links to Additional Background Reading

Oil Economics

John V. Mitchell, "A new political economy of oil," (*The Quarterly Review of Economics and Finance* 42 (2002), pp. 251-272. (http://sciserver.lanl.gov/pdflinks/03041210563510830--journals--10629769--v42i0002--251_anpeoo.pdf)

J. Bielecki, "Energy security: is the wolf at the door?" (*The Quarterly Review of Economics and Finance* 42 (2002), pp. 235-250. (http://sciserver.lanl.gov/pdflinks/03041210563310829--journals--10629769--v42i0002--235_esitwatd.pdf)

DOE, EIA, "Rules-of-Thumb for Oil Supply Disruptions," Oct. 18, 2002. (http://www.eia.doe.gov/emeu/security/rule.html)

Benjamin Zycher, "A Counterintuitive Perspective on Energy Security (Presentation at United Nations Economic Commission for Europe Twelfth Annual Session on Sustainable Energy, Geneva, Nov. 20. (www.unece.org/energy/presentations/RT_Zycher_Rand.pdf)

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Arjun Makhijani, Securing the Energy Future of the United States: Oil, Nuclear, and electricity Vulnerabilities and a post-September 11, 2001Roadmap for Action, "Chapter 2: Energy System Security Criteria" (Takoma Park, Maryland: Institute for Energy and Environmental Research, November 2001). (http://www.ieer.org/reports/energy/bushch2.html)

National Energy Policy Development Group, "Chapter 8: Strengthening Global Alliances: Enhancing National Energy Security and International Relationships," *Reliable, Affordable, and Environmentally Sound Energy for America's Future* (May, 2001). (http://www.whitehouse.gov/energy/Chapter8.pdf)

Anders Hove, "Oil and U.S. Policy in the Middle East," (rev. July 25,2002). (http://the-tech.mit.edu/~derz/Oil/forpol.pdf)

Anders Hove, "The Road to Energy Security" (July 2002). (http://the-tech.mit.edu/~derz/Oil/oilindependence.pdf)

Standing Group on Long-Term Co-operation, International Energy Agency, "Moving to a Hydrogen Economy: Dreams and Realities," 30 January 2003 (IEA/SLT(2003). (http://www.energycooperation.org/PDF/MovingtoaH2Economy-IEA.pdf)

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Richard Sokolsky, Stuart Johnson, and F. Stephen Larrabee, *Persian Gulf Security: Improving Allied Military Contributions* (Santa Monica: RAND, Report MR-1245-AF, 2001). http://www.rand.org/publications/MR/MR1245/.

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Daniel Hirsch, David Lochbaum & Edwin Lyman, "The NRC's Dirty Little Secret," " *Bulletin of the Atomic Scientists*, May/June 2003. (http://www.thebulletin.org/issues/2003/mj03/mj03hirsch.html)

President's Commission on Critical Infrastructure Protection. "Appendix A, Sector Summary Reports: Energy," *Critical Foundations: Protecting America's Infrastructures* (October 1997). (http://www.ciao.gov/resource/pccip/appa.pdf)

Climate Change

International Panel on Climate Change, *IPCC Third Assessment Report: Climate Change 2001*. (Various components at http://www.ipcc.ch/pub/reports.htm)

A. Barrie Pittock, "What We Know and Don't Know about Climate Change: Reflections on the IPCC TAR," *Climatic Change*, Volume: 53, Issue: 4, June 2002, pp. 393-411.

(http://sciserver.lanl.gov/pdflinks/03040715540814009--journals--01650009--v53i0004--393_wwkadkcrotit.pdf)

van den Hove, Sybille; Le Menestrel, Marc; de Bettignies, Henri-Claude, "The oil industry and climate change: strategies and ethical dilemmas," *Climate Policy*, Vol: 2, Issue: 1, May, 2002, pp. 3-18. (http://sciserver.lanl.gov/pdflinks/03040716071615198--journals--14693062--v02i0001--3_toiaccsaed.pdf)
Lindzen, R.S., Chou, M.-D. and Hou, A.Y. 2001. Does the earth have an adaptive infrared iris? *Bulletin of the American Meteorological Society* **82**: 417-432. ((http://www-eaps.mit.edu/faculty/lindzen/adinfriris.pdf)
C. D. Idso and K. E. Idso, "Energy, Carbon Dioxide and Earth's Future: Pursuing the Prudent Path." http://www.co2science.org/print.php3
Solutions and Policy Proposals
Kyle McSlarrow, Deputy Secretary, DOE, "Testimony" on Comprehensive National Energy Policy before the U.S. House of Representatives, Committee on Energy and Commerce, Subcomittee on Energy and Air Quality, March 5, 2003.
(http://energycommerce.house.gov/108/hearings/03052003Hearing801/McSlarrow1311.htm
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