Δ The Triangle Papers: 61

Energy Security and Climate Change

A Report to
The Trilateral Commission

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The Trilateral Commission was formed in 1973 by private citizens of Europe, Japan, and North America to foster closer cooperation among these three democratic industrialized regions on common problems. It seeks to improve public understanding of such problems, to support proposals for handling them jointly, and to nurture habits and practices of working together. The Trilateral countries are nations in Europe, North America, and Pacific Asia that are both democratic and have market economies. They include the member and candidate member nations of the European Union, the three nations of North America, Japan, South Korea, the Philippines, Malaysia, Indonesia, Singapore, Thailand, Australia, and New Zealand.

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1

Priority Energy Security Issues

John Deutch

Energy markets create economic interdependence among Trilateral countries and between Trilateral countries and the rest of the world. Energy is an important domestic political issue because our economies rely on access to dependable supplies of energy and because consumers and economies are sensitive to energy costs. Economies can prosper when energy costs move higher, but the reality and perception of price instability create uncertainty that affects consumer spending and dampens investment. Thus, domestic energy policies have international consequences, and international developments affect domestic economies.

The term "energy security" is intended to convey the connection between the economic activity that occurs in both domestic and international energy markets and the foreign policy response of nations (apart from the fundamental connection between national security and a healthy economy). Increasingly, both governments and the public recognize that the linkage to national security matters must be evaluated alongside economic considerations in adopting energy policies. For example, efforts to prevent Iran's nuclear program from leading to a nuclear weapons capability, taken together with the importance that Iranian oil exports (now about 3 million barrels per day) have for the world oil price, and the potential for Iran to heighten or dampen civil violence and unrest in Iraq and elsewhere in the Middle East vividly illustrate the difficulty and complexity of the energy security linkages.

The energy issue is not new to the Commission. In 1998 the Trilateral Commission published a comprehensive energy report authored by William F. Martin, Ryukichi Imai, and Helga Steeg, entitled *Main-*

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taining Energy Security in a Global Context,[1] and at the 2006 Tokyo Plenary Meeting, Steve Koonin spoke about available technology choices for meeting future energy needs.[2] In 2007, in Brussels, the Trilateral Commission continues its consideration of energy. This background paper draws on thirty years of involvement with these issues, including as a government official in the U.S. Department of Energy and Department of Defense, research and teaching about energy technology at the Massachusetts Institute of Technology (MIT), and involvement with many private energy firms. This paper aspires to deepen the analysis of some of the key energy security issues we face today:

- Oil and gas import dependence;
- Energy infrastructure vulnerability;
- Global warming; and
- The future of nuclear power.

In addressing each of these four topics, the connection between energy and security, actions that Trilateral countries should take, and the interactions between the four issues are identified.

Before beginning, two points require emphasis: first, progress on each of these issues requires a heightened level of international cooperation; and second, enlightened common action by nations can substantially lower the cost of adapting to our energy future. This is true for Trilateral countries and the international community. Moreover, Trilateral members, in their relationships with their colleagues and their governments, can make a difference in how well and quickly we act.

The United States and, I suspect, most Trilateral countries have made little progress in adopting measures recognized as necessary to address effectively the four key energy security challenges listed above. For example, the United States does not have in place a policy process that harmonizes the foreign and domestic aspects of energy policy. There are two underlying causes. First, progress on each of these key issues requires sustained policies over a long period of time—decades rather

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1 William F. Martin, Ryukichi Imai, and Helga Steeg, *Maintaining Energy Security in a Global Context* (Washington, D.C.: Trilateral Commission, 1998), www.trilateral.org/projwork/tfrsums/tfr48.htm.

2 Steve E. Koonin, "In Search of New Global Frameworks for Energy Security," in *Challenges to Trilateral Cooperation* (Tokyo: Trilateral Commission, 2006), 3, www.trilateral.org/annmtgs/trialog/trlglist.htm.

than years. As prices and events change, the public's attention and the attention of their elected representatives waxes and wanes. The public memory of Indian, Pakistani, and North Korean nuclear tests dims, while the potentially adverse consequences of each of these nations possessing a nuclear capability do not. Irreversible global climate change will not be apparent until many years after current elected officials leave office, which reduces the incentive to allocate scarce resources for needed investment in mitigating greenhouse gas emissions.

The second and related reason is that elected officials tend to avoid speaking plainly about energy issues. The public understandably wants cheap and dependable energy that permits an improved lifestyle and neither harms the environment nor depends on foreign sources. Simultaneously satisfying all these conditions is difficult, if not impossible, especially since, in a market-based energy economy, energy imports rise when imports are cheaper for the consumer than domestic energy alternatives. To quote my MIT colleague, economist Lester Thurow:

> It is only when we demand a solution with no cost that there are no solutions.

In the United States and, I surmise, elsewhere, political figures seem unable to resist the temptation to tell the public what they want to hear. One hears the call for energy independence—an unattainable concept—and arbitrary goals for renewable energy or efficiency improvements that are not based on realistic assessment of either economics or technology or on a willingness to put in place policy measures such as energy consumption or carbon emission taxes that would catalyze the transformation to a new global system of energy supply and use.[3] It is up to leaders in Trilateral countries to urge their governments to take urgently needed action.

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3 A particularly embarrassing example for me is one of the new initiatives in "Six for '06" announced by congressional Democrats (http://democrats.senate.gov/agenda/) immediately after their November 2006 midterm election sweep, which states:

> ENERGY INDEPENDENCE—LOWER GAS PRICES: Free America from dependence on foreign oil and create a cleaner environment with initiatives for energy-efficient technologies and domestic alternatives such as biofuels. End tax giveaways to Big Oil companies and enact tough laws to stop price gouging.

Oil and Gas Import Dependence

Import dependence has both economic and political consequences.[4] Here we are concerned with the political consequences that result from both the reality and perception of anticipated economic consequences.

The trend in world oil supply and demand under business-as-usual assumptions is clear.

Demand and Supply of Oil

The U.S. Department of Energy's Energy Information Administration (EIA) projects in the *International Energy Outlook 2006*[5] an increase in world oil consumption from 80 million barrels of oil per day (MMBOD) in 2003 to 118 MMBOD in 2030, that is, an average annual increase of 1.4 percent, accompanied by an uncertain real price increase. (The EIA considers a range of prices from $38 per barrel to $96 per barrel, with $57 per barrel in the reference case; all prices are in real 2004 dollars.)

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4 This section relies heavily on the recent Council on Foreign Relations report, *National Security Consequences of U.S. Oil Dependency* (New York: Council on Foreign Relations, October 2006), www.cfr.org/publication/11683/. James Schlesinger and I cochaired the independent task force that prepared this report.

5 *International Energy Outlook 2006* (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, June 2006), Chap. 3, http://www.eia.doe.gov/oiaf/ieo/pdf/oil.pdf. Table N1 provides additional information.

Table N1. World Oil Consumption by Region and Country Group, 2003 and 2030, million barrels per day

Regions and country groups	2003	2030
North America	24.2	33.4
Non-OECD Asia	13.5	29.8
OECD Europe	15.5	16.3
OECD Asia	8.8	10.1
Central and South America	5.3	8.5
Middle East	5.3	7.8

Source: *International Energy Outlook 2006* (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, June 2006), DOE/EIA-0484(2006), www.eia.doe.gov/oiaf/ieo/excel/figure_27data.xls.

Asian countries, including China and India, that are not members of the Organization for Economic Cooperation and Development (OECD) account for 43 percent of the increase in consumption.[6] Importantly, EIA projects a non-OECD Asia oil consumption growth rate of 3 percent, so that by 2030, non-OECD Asia will account for about 28.1 percent of world consumption, compared with 18.6 percent in 2003.[7]

Most of the world's oil reserves are in the Middle East and in Organization of the Petroleum Exporting Countries (OPEC), as shown in table 1 on page 6.

Accordingly, importing nations for the foreseeable future will rely in large measure on oil from these countries.

Between 2003 and 2030, the world oil trade is expected to increase:

- In 2003, total world oil trade consisted of 53 MMBOD. Of this amount, 32 MMBOD came from OPEC, including 22.5 from the Persian Gulf region. North America imported 13.5 MMBOD, and non-OECD Asia imported 9.9 MMBOD, with China accounting for 2.8 MMBOD of that total.
- In 2030, it is estimated that total world oil trade will be 77 MMBOD. Of this amount, it is estimated that OPEC will produce 48.5 MMBOD, including 34 MMBOD from the Persian Gulf Region. North America is projected to import 19 MMBOD, and non-OECD Asia 22 MMBOD, with China accounting for 11 MMBOD of that total.

These data suggest why there is increasing concern about the security aspects of dependence on oil and gas imports.

On the demand side, in the absence of an extended global recession, there appears to be no diminution in the pace of increase in world oil consumption. The new, rapidly growing emerging economies such as China and India are becoming major importers of oil. The sharp increase in oil prices that occurred in early 2006 was the first price shock that can be characterized as demand driven; Hurricane Katrina and supply concerns with Nigeria and Venezuela were also factors. The economic consequence is the effect of price shocks on the economies of importing countries, although OECD economies have recently gone through a major price increase with little effect on their economies.

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6 Ibid., 25.

7 Ibid., 27.

Table 1. World Oil Reserves, by Country, as of January 1, 2006, billion barrels

Country	Oil reserves
Saudi Arabia	264.3
Canada	178.9
Iran	132.5
Iraq	115.0
Kuwait	101.5
United Arab Emirates	97.8
Venezuela	79.7
Russia	60.0
Libya	39.1
Nigeria	35.9
United States	21.4
China	18.3
Qatar	15.2
Mexico	12.9
Algeria	11.4
Brazil	11.2
Kazakhstan	9.0
Norway	7.7
Azerbaijan	7.0
India	5.8
Rest of world	68.1
World total	1,292.5

Source: "Worldwide Look at Reserves and Production," *Oil & Gas Journal* 103, no. 47 (December 19, 2005): 24–25.

On the supply side, importing nations will remain dependent to a large extent on oil coming from politically unstable parts of the world—the Persian Gulf, for example—and from suppliers such as Iran, Russia, and Venezuela that may actively oppose the interests and policies of Trilateral countries. Non-OPEC production between 2003 and 2030 is estimated to fall slightly as a proportion of all exports. The concern here is that effective control of supply and price by a cartel of exporting countries—OPEC—could potentially be used as a political instrument to influence, for example, the Palestine-Israel question. The oil trade transfers significant wealth to producer countries such as Iran that do not share the values or interests of Trilateral countries, and petrodollars can be used to support terrorist organization or efforts to acquire weapons of mass destruction, as the was the case in the 1980s with Libya and Iraq.

In addition, concerns are increasing about the functioning of oil and gas markets, especially because there has been a movement away from transparent markets governed by commercial considerations to state-to-state agreements between the national oil companies (NOCs) of the major resource holders (MRHs) and the new rapidly growing emerging economies.

There has been a major shift in oil reserves and production from the international oil companies (IOCs) to the NOCs. In the early 1970s, the IOCs controlled about 80 percent of reserves and production, while NOCs controlled 20 percent. Today that proportion is about reversed. A 2005 article in the *Washington Post* included a stark graphic that showed the largest non-state-controlled IOC, ExxonMobil, was number fourteen on a list of the top twenty-five MRHs.[8]

While there is a wide variability in the capacity and efficiency of the NOCs to explore, produce, and market their hydrocarbon reserves, it is likely that NOCs will become progressively more important on the supply side of the market. If IOCs are to prosper, they will need to adapt their traditional approach that seeks ownership and control of reserves in MRH countries.

The MRHs are quite clear that they intend to use their resources to advance political objectives. The rhetoric of Iran and Venezuela is especially strident. But Russia has also made plain that centralizing control over its petroleum industry is intended to give Russia political leverage—a message that especially threatens Europe, with its great dependence on Russian gas imports.

The net result of the combination of more muscular NOCs and new consumers that are unsure about the source of their future supply is an increase in state-to-state agreements, with new users seeking to

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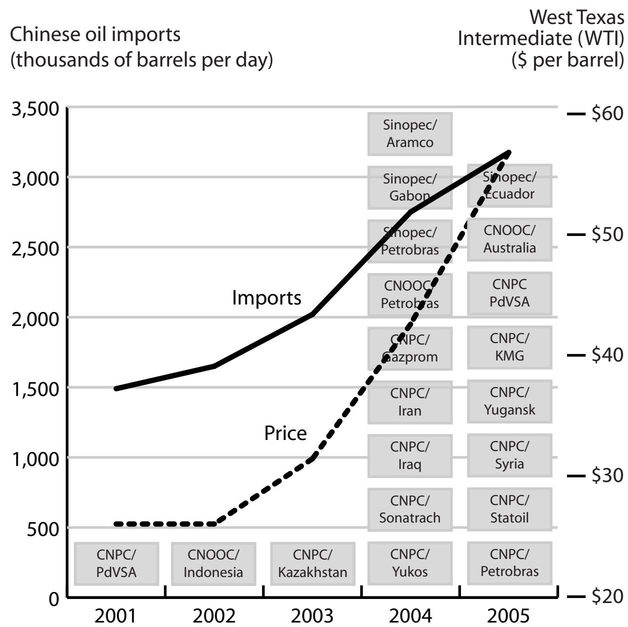
8 Justin Blum, "National Oil Firms Take Bigger Role: Governments Hold Most of World's Reserves," *Washington Post*, August 3, 2005, Sec. D, http://www.washingtonpost.com/wp-dyn/content/article/2005/08/02/AR2005080201978_pf.html.

Figure 1. Trends in Rising Chinese Oil Imports, Prices, and Number of Political Oil Deals



Sources: Sinopec Corp., CNOOC Limited, and China National Petroleum Corporation. Price data from *BP StatisticalReview of World Energy 2006.* Import data from *EIA China Country Analysis Brief,* August 2006. As cited in *National Security Consequences of Oil Dependency* (New York: Council on Foreign Relations, October 2006).

lock up supply. These agreements frequently involve political concessions and nonmarket considerations that are quite different from what is expected in a conventional commercial transaction; the Chinese arrangements in Africa with Sudan and Angola are frequently cited. Figure 1 vividly illustrates the growth in Chinese offshore oil activity.

These cases are the consequence of China's policy of "going out" for resources globally.[9]

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9 Aaron L. Friedberg, "'Going Out': China's Pursuit of Natural Resources and Implications for the PRC's Grand Strategy," *NBR Analysis* 17, no. 3 (September 2006), 21<em>30, www.nbr.org/publications/issue.aspx?ID=392.

The objection to state-to-state agreements is not that oil is taken off the open market—to date the quantities tied up are small—or that new consumers are paying too high a price to lock up oil supplies, but instead the objection is to the use of oil as a political instrument by those whose political purposes may run counter to the interests of Trilateral countries. For example, Angola provides China with 15 percent of its total oil consumption. In May 2006, Angola's Sonangol and China's Sinopec signed a multibillion-dollar agreement to develop jointly offshore blocs with reserves estimated at 4.5 billion barrels (China beating out India in this bid). Since 2004, in parallel, the Chinese government has extended extensive technical assistance to Angola, including a soft loan of $4 billion and pledges to invest $400 million in Angola's telecommunications sector and to upgrade Angola's military communications network. China imports about 10 percent of its oil from Sudan, where it has major investments; China is reported to be Sudan's biggest supplier of arms and military equipment.

Natural Gas

The outlook for global natural gas demand and supply lags oil in terms of the security concerns based on import dependency, and it shows greater regional variation. In brief, four countries—Russia, Iran, Qatar, and Saudi Arabia—account for 60 percent of world gas reserves. Both OECD and non-OECD countries, especially non-OECD Asia, are projected to increase their consumption of gas over time, increasingly through international trade.

This projected international trade may occur by pipeline, as from Canada to the United States or from Russia to Europe; by liquefied natural gas (LNG), as from Indonesia to Japan or Trinidad to the United States; or by conversion of gas-to-liquefied (GTL), for example, natural gas converted to methanol, in locations such as offshore West Africa, where large reserves of gas are "stranded" far from markets.

Natural gas is an attractive fuel because its production and use is relatively environmentally "clean." The price of natural gas is likely to equilibrate, on average over time, to the price of oil at the point of use—"the burner tip"—because natural gas is a direct substitute for refined oil in industry.

In East Asia, intense competition is likely among Japan, South Korea, Taiwan, and China for available natural gas supplies. China and Japan will compete for control of natural gas pipeline routes from Central Asia to the Pacific to lock in and increase sources of supply.

Europe already is heavily dependent on natural gas imports, especially from Russia. Gazprom has shown its willingness to cut off gas supplies to Ukraine and Belarus on the grounds that the countries are not paying market prices, but the lesson is not lost on Europeans who depend on a reliable supply from Russia. Some of the pipelines that carry Russian gas to Europe transit Ukraine and Belarus, so a dispute between Russia and these countries could easily affect gas delivery to Europe.

North America is certain to become a net importer of natural gas in the near future. The good news is that the natural gas pipeline system and market that serves Canada, Mexico, and the United States has become more integrated. The bad news is that over time North America will increasingly depend on LNG imports. These LNG imports, the source of supply at the margin, will determine (allowing for transportation and processing costs) the price of natural gas in North American markets, as opposed to the cost of North American production.

Effect of Oil and Gas Dependence on International Security

The chronic (and growing) dependence on imported hydrocarbons has many implications for the conduct of foreign affairs by individual nations and for international security.

Because increased demand is recognized as inevitable, at least in the short run, countries will become increasingly intent on assuring a reliable supply and hence sensitive to indications that world oil and gas markets are becoming less open and transparent. Importing countries inevitably will adjust their policies and international relationships to accommodate the interests of those countries that supply their oil and gas. The competition for supply among OECD countries and between OECD and non-OECD countries will increase, giving rise to heightened tensions. Africa and Central Asia will become particular areas for competition. In Central Asia, competition for hydrocarbons and pipeline routes (going east or west) will present Russia and Iran with opportunities to forge new advantageous relationships with China, Japan, India, and others.

Because China is growing so rapidly, its need for hydrocarbon imports will be correspondingly great. Its quest for these resources is sure to add strain in the relations between China and its East Asian neighbors and between China and the United States.[10] The intensely adverse U.S. reaction to the offer by the Chinese National Offshore Oil

Company (CNOOC) to buy the offshore assets of Union Oil of California (UNOCAL) and the incorrect belief that Chinese demand caused the 2005–2006 increase in world prices (or, if you believe this, the more recent decline in prices) indicate how the energy issue can exacerbate an already complicated relationship between these two countries. The U.S. reaction to the CNOOC offer to buy UNOCAL is particularly unfortunate because it contradicts U.S. policy elsewhere in the world of support for opening the oil sector of other countries—for example, Russia—to investment. The truth is that China's approach to its participation in the world oil and gas market is evolving; influencing its evolution is important to Trilateral countries.

Responding to the foreign policy challenges caused by these features of world oil markets would be easy if energy security were the sole or priority concern. But energy security is just one of many foreign policy objectives of Trilateral countries. Our energy security objectives must be balanced against combating terrorism; slowing the spread of weapons of mass destruction; and encouraging democracy and human rights, economic growth, and environmental protection. Energy dependence constrains Trilateral countries in pursuing other important foreign policy objectives.

Response of Trilateral Countries

Any response must be based on three realities.

First, the world is running out of low-cost oil; over time the real price of oil will go up. From time to time the price of oil may decline, but over the long haul, the world is on a staircase of rising prices for hydrocarbon fuel.

Second, Trilateral countries and other large oil-importing countries, such as China and India, will, for at least the next several decades, remain dependent on oil from the Persian Gulf—Iran, Iraq, Saudi Arabia, and Kuwait.

Third, we must begin a transition away from a petroleum economy. This is a long-term problem with no short cuts. Investments must be made today if we are to have choices in the future.

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10 An important analysis is Kenneth Lieberthal and Mikkal Herberg, "China's Search for Energy Security, Implications for U.S. Policy," *NBR Analysis* 17, no. 1 (April 2006), www.nbr.org/publications/issue.aspx?ID=217.

Foreign policy measures. These three realities point the way for what Trilateral countries should do. I suggest four measures intended to influence international energy developments. Even if successful, taken together these measures serve only to improve our capacity to manage oil and gas import dependence; they do not offer the prospect of eliminating energy dependence or even reducing the expected dependence to a level that qualitatively would change security concerns for the foreseeable future.

1. Trilateral countries have common interests with the new, large, emerging economies. This means the International Energy Agency (IEA) should be broadened to include new significant consumers such as China and India because, ultimately, all consumers will benefit from a level playing field where there is competition for resources on commercial terms.
2. When expanded, the IEA should address common policies with regard to national stockpiles and response to price shocks. IEA members should continue to advocate that countries not subsidize internal oil and gas prices. Permitting prices to rise to world levels is a necessary, but perhaps not a sufficient, step toward limiting demand growth. If there are groups within a country—for example, low-income families and the elderly—that are especially hurt by higher energy prices, individual countries will, and should, adopt targeted assistance programs rather than further distort markets.
3. Trilateral countries have an interest in maintaining and increasing oil and gas production everywhere in the world.

    a. Trilateral countries should work together to encourage stability in the Persian Gulf. This means that diplomacy, trade, and economic policies need to balance the important objective of continued production with other objectives such as human rights and democratization.

    b. Trilateral countries should continue to encourage production in non-OPEC countries. This has long been an objective of OECD countries and has met with limited success. The proportion of oil produced by non-OPEC countries is unlikely to increase dramatically, but the effort should continue.

    c. Trilateral countries need to encourage production where possible in their own countries. For example, Canada's huge tar sands resources (330 billion barrels) are expected to reach a production level of between 2 and 4 million barrels per day in the next fifteen years.[11] Production should also be encouraged in the North Sea. The United States should also increase domestic oil and gas production from some areas in Alaska, the Gulf of Mexico, and the Atlantic and Pacific coasts that are currently off-limits because of environmental concerns. While incremental U.S. production will be only a small part of total supply, it is difficult to see how the United States or other Trilateral countries can convince others to expand production without making any effort to increase production at home.

4. Trilateral countries should encourage responsible governance in producing countries in West Africa generally and in Ecuador in South America. The motivation here is not altruism but rather that political and social stability are necessary for continued, even expanded, oil and gas production. Stability requires some use of oil revenues to improve the economic and social circumstances of ordinary people. The expanding energy sector in Africa presents significant challenges.[12]

The leverage of Trilateral countries on international energy developments is limited. In part the limitation follows from dependence and in part from the fact that energy is only one of many foreign policy objectives. Some advance the notion that Trilateral countries can and should adopt more aggressive policies, such as by establishing a linkage between cooperative behavior on both energy and nonenergy matters by a producer country, and access to technology, domestic markets, and trade with the importing countries. There may be particular situations where such a tactic might work to advantage, but the approach is unlikely to be widely effective and it would be unwise because it is a move away from open and transparent world markets.

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11 See "CAPP Releases 2006 Canadian Crude Oil Forecast," Canadian Association of Petroleum Producers, May 17, 2006, www.capp.ca/default.asp?V_DOC_ID=1169. Current tar sands production by strip mining and in situ methods such as steam-assisted gravity drive (SAGD) is about 900,000 barrels per day.

12 See *More Than Humanitarianism: A Strategic U.S. Approach toward Africa* (New York: Council on Foreign Relations, January 2006), http://www.cfr.org/publication/9302/more_than_humanitarianism.html. The report includes a description of Chinese activities in Africa.

Domestic policy measures. While Trilateral country leverage on international oil matters may be limited, Trilateral countries can do a lot more with domestic policies. Trilateral countries should be focused on adopting domestic policies that begin the long process of moving away from a petroleum-based economy. I suggest three priority domestic policy measures.

1. The highest priority should be to maintain a high price on liquid fuel, because this encourages efficiency and fuel switching, dampens demand, and stimulates innovation. High liquid fuel prices are in place in Europe and Japan, but not in the United States.[13] I favor adoption of an additional tax in the range of $1.00 per gallon imposed on motor gasoline, diesel, and other petroleum

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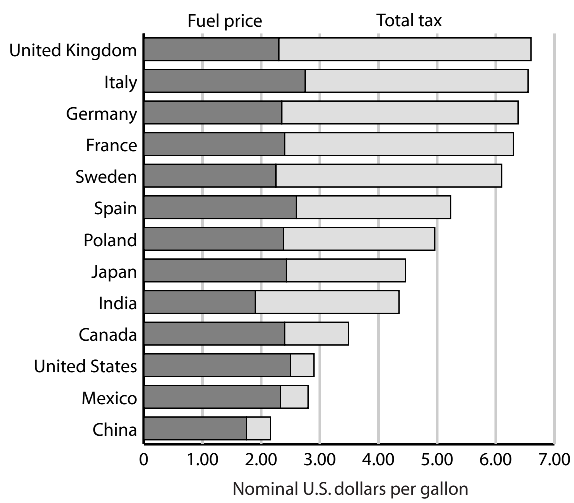
13 Figure N1 from Cambridge Energy Research Associates vividly makes the point that the United States (and China) lag behind the rest of the world in petroleum taxes.

Figure N1. Gasoline Prices and Taxes in Selected Countries, 2006



Sources: Cambridge Energy Research Associates; *Energy Prices and Taxes,* International Energy Agency, third quarter 2006. See http://www2.cera.com/ gasoline/press/.

Notes: Japan and China prices are for 91 RON unleaded. India price is for 91 RON leaded. Canada price is for 92 RON unleaded. U.S. price is for 87 octane (R+M)/2 basis. Data are third quarter 2006 averages, as available.

products at a time when pump prices are falling, so the impact on the public will be less. A tax of this level would raise considerable revenue, in excess of $150 billion per year, which should be allocated for three purposes: countervailing reduction in other taxes; increased support for energy research, development, and demonstration (RD&D); and impact assistance for those most adversely affected by the tax.

Many will note the political difficulty, if not impossibility, of the U.S. Congress assessing such a tax; thus, there is interest in alternative approaches such as tradeable gasoline rights[14] or tightening of present corporate average fuel economy (CAFE) standards. CAFE standards, because they mandate fuel economy, only indirectly reduce gasoline consumption. Some combination, rather than any one of these three measures, may be more politically feasible.

2. The second priority of Trilateral countries should be to adopt a much larger and more ambitious RD&D effort to create future options for new liquid fuels or substitutes for liquid fuels. One approach is to develop new technologies that use these fuels more efficiently. The other approach is to develop new technologies for alternatives to liquid fuels. Three deserve mention: synthetic liquids and gas from shale and coal; biofuels such as ethanol from biomass; and alternative nonfossil, electricity generation-based transportation systems.

    a. *Synthetic liquids and gas from shale and coal.* As conventional, low-cost sources of oil and gas are depleted, there will be a steady progression to more costly fossil sources of liquid fuels. The first stage will be unconventional oil and gas resources, such as coal bed methane and tar sands. The next stage will use the considerable shale and coal resource base to produce synthetic fuels. I was deeply involved in the launch of the ill-fated U.S. Synthetic Fuels Corporation of the 1970s, and today's efforts can learn much from this experience. Figure 2 gives a highly schematic view of how synthetic fuels are produced.

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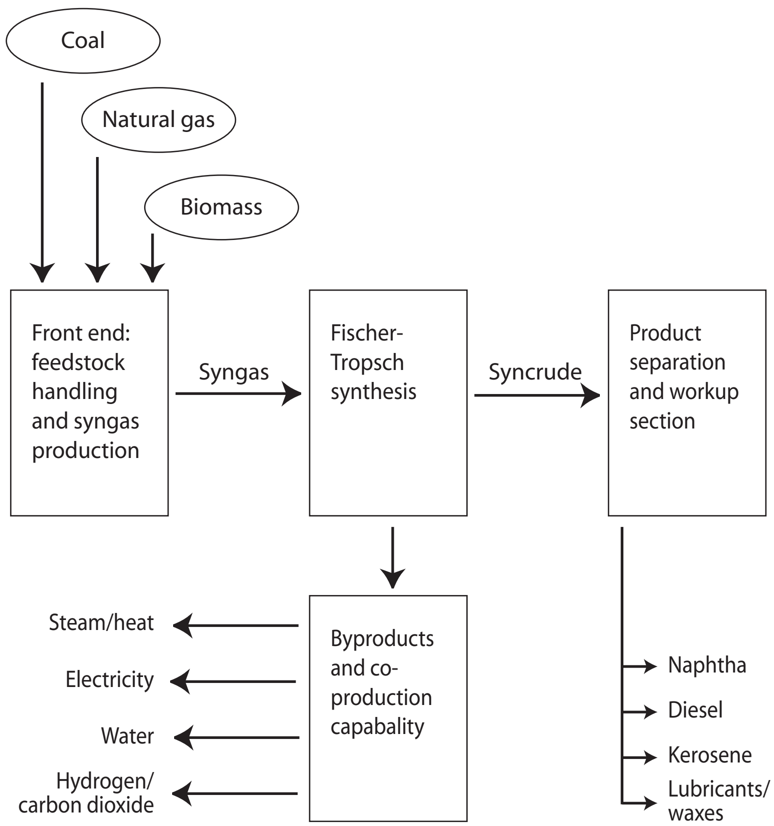
14 My friend and distinguished Trilateral Commission member, Martin Feldstein, is the leading proponent of this approach; see "Tradeable Gasoline Rights," *Wall Street Journal,* June 5, 2006, www.nber.org/feldstein/wsj060506.html.

Figure 2. System Elements for Production of Synthetic Fuels from Coal, Natural Gas, and Biomass



Source: *Annual Energy Outlook 2006, with Projections to 2030,* report no. DOE/EIA-0383(2006) (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, February 2006), 54, figure 19, http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2006).pdf.

Synthetic fuels face two challenges. The first is cost. The capital cost is high, in the range of $50,000–$75,000 per barrel per day capacity, which in turn leads to high product costs. For example, a first-of-a-kind shale plant has been estimated to be able to produce synthetic liquid in the range of $70–$95 per barrel (2005 dollars) over the life of the plant.[15] The cost of initial plants to produce synthetic liquids from coal will be in a comparable range, depending on coal cost and quality. As industry capacity expands and there is learning by doing, these costs should come down, perhaps by $20–$30 per barrel, as industrial capacity expands.

The second challenge to synthetic-fuels production from shale and coal is environmental. These conversion projects will require attention to air and water quality, waste material disposal, and land remediation. On a large scale, carbon dioxide (CO_2) emissions are also of concern. The conversion of coal to synthetic oil, for example, involves the formation of between two and three molecules of CO_2 for every atom of carbon in the oil.[16] Thus, the CO_2 emissions of synthetic oil can be double or more (after by-product credit) compared with conventional oil. If (as discussed later) global constraints on carbon emissions are adopted in order to reduce the threat of global warming, carbon capture and sequestration (CCS) might be required when producing synthetic fuels from coal and shale, driving costs much higher.

The *Annual Energy Outlook 2006* (published by the Energy Information Administration of the U.S. Department of Energy), in the high price case, assuming the use of underground mining with surface retorting, estimates that U.S. oil shale production will begin in 2019 and grow to 410,000 barrels per day by 2030.[17] *Annual Energy Outlook 2006* projects U.S. coal-to-liquids production in the range 800,000 to 1.7 million barrels per day in 2030, depending upon oil price assumptions. Worldwide coal-to-liquids production in 2030 is estimated to be in the range of 1.8 to 2.3 million barrels per day.[18] If shale oil production includes CO_2 capture, the cost rises substantially.

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15 James T. Bartis et al., *Oil Shale Development in the United States: Prospects and Policy Issues* (Santa Monica, Calif.: RAND Corp., 2005), www.rand.org/pubs/monographs/2005/RAND_MG414.pdf.

16 I stress that CO2 emissions from synthetic-fuels production depend on the technology employed.

17 *International Energy Outlook 2006*, 54.

18 Ibid., 55.

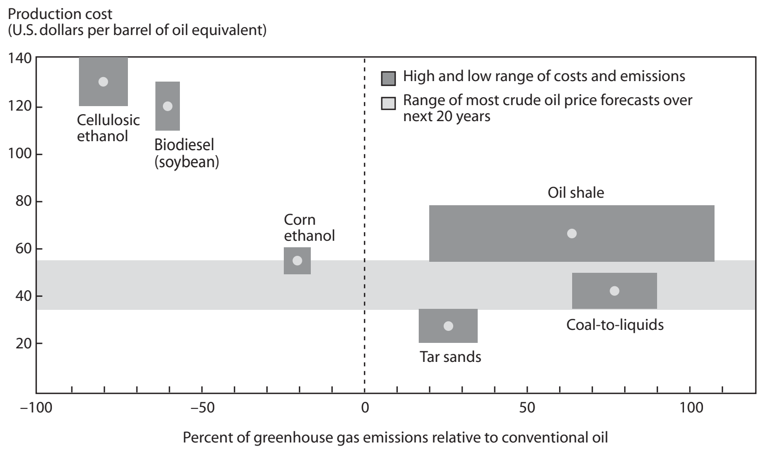
b. *Biofuels.* Biofuels from biomass also have significant potential to displace a portion of petroleum-based liquid fuels. In countries that have a highly industrialized agricultural sector, the production of ethanol or biodiesel from food crops will not be economic without government subsidies. Moreover, although it remains hotly debated in the United States, ethanol produced from corn or sugar likely requires two-thirds of a barrel of the oil equivalent of the natural gas and oil needed to produce one barrel of oil equivalent ethanol (after allowance for by-product credits) because of the energy intensity of cultivation and energy requirement for fermentation and distillation.

In countries with a more favorable climate and a less energy-intensive agricultural sector, such as Brazil, the economics of conversion of food crops to biofuels may be different than in the United States. The United States, rather foolishly, places 5.5 cents per gallon tariff on both sugar and ethanol imports in order to protect U.S. ethanol distillers and corn farmers from this competition.

The situation with regard to the potential for the production of biofuels such as ethanol or butanol from cellulosic biomass, such as agricultural waste, corn stover, switch grass, and poplar, is quite different. These crops are fast growing and are not cultivated in an energy-intensive way, neither do they command the high price of a food crop. Thus, there is the potential for economic production of biofuels. The biomass can be converted to liquid fuel in two ways. The first is indirectly through gasification, as indicated in figure 2.

The second approach uses modern biotechnology to engineer new organisms that will efficiently and economically digest the cellulose and hemicellulose into usable liquid products. (Native organisms easily digest the starch-based sugars in food-based crops.) This approach is receiving great attention today, but there are technical challenges. For fermentation, cellulosic materials require severe conditions to separate the cellulose and hemicellulose from the feed-starting material. The biotechnology and metabolic engineering required to produce biofuels remain to be demonstrated on an industrial scale. Several corporations, including BP, Chevron, and DuPont, have large programs, and in the United States many biotech startups are exploring various aspects of this biomass-to-

Figure 3. Oil Alternatives: Costs and Emissions Vary Widely



Source: Richard G. Newell, "What's the Big Deal about Oil: How We Can Get Oil Policy Right," *Resources,* No. 163 (Fall 2006): 9, www.rff.org/Documents/Rff-Resources-163.pdf.

biofuels approach. Under optimistic assumptions, the cost per barrel oil equivalent for cellulosic ethanol in the future is in the range of $40 per barrel, so there is genuine reason for enthusiasm here.[19]

Annual Energy Outlook 2006 projects 700,000–900,000 oil equivalent barrels per day of U.S. ethanol production and 1.7–3.0 million barrels per day oil equivalent (including biodiesel) worldwide production in 2030, depending upon world oil prices.[20] There are limits, however, to ultimate production—perhaps 30 million barrels per day worldwide—because of land and water availability. Of course, aquaculture is another potential source of biomass.

A recent publication by Resources for the Future provides a useful summary of the range of estimates of the costs and greenhouse gas emissions of liquid fuel alternatives relative to conventional oil (figure 3).

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19 See John Deutch, "Biomass Movement," *Wall Street Journal,* May 10, 2006, http://online.wsj.com/article/SB114722621580248526.html.

20 *International Energy Outlook 2006,* 58.

c. *Alternative electricity-based transportation systems.* Alternative electricity-based transportation systems offer another path to replacing liquid-fueled transportation systems. Both mass transit rail-based systems and electric hybrid or all-electric cars are interesting possibilities; the latter would benefit greatly from an improvement in batteries or other methods of electricity storage.

   This pathway, of course, trades off petroleum dependence for electricity generation. I discuss later the security concerns from coal-fired electricity generation (global warming) and from nuclear power (proliferation).

3. The third domestic priority for Trilateral countries is to explore new ways of managing the energy RD&D process. Successful innovation in the energy sector requires a significant research and development effort, accompanied by a demonstration stage undertaken for the purpose of demonstrating the technical feasibility, cost, and environmental character of new technology. The demonstration phase is necessary because in most OECD countries, energy production and distribution are done by the private sector. Private firms and the financial institutions that provide firms with the capital needed for the massive investments required will not adopt unproven technology. Some form of government assistance is likely to be necessary for first-of-a-kind plants.[21]

   The mechanism for public support for technology change of the kind that is needed differs among Trilateral countries. The European Union, Japan, and the United States have very different procedures for deciding how to share the costs of RD&D between the government and the private sector. Nevertheless, there may be attractive opportunities for cooperation among Trilateral countries—one long-term example is cooperation on fusion energy research.

21 Much has been written about how the process of government encouragement of civilian technology might be improved. An old but nevertheless still relevant discussion is given in *The Government Role in Civilian Technology: Building a New Alliance*, the report of a panel chaired by Harold Brown (Washington, D.C.: National Academies Press, 1992), http://books.nap.edu/catalog.php?record_id=1998.

Energy Infrastructure Protection

As energy use expands and resources originate at progressively greater distance from users, the energy infrastructure that supports energy distribution becomes more vulnerable to damage from nature, technical failure, or human causes.

Natural disasters. As low-cost oil and natural gas resources are depleted, production facilities move to more extreme environments such as production platforms operating in the Arctic or offshore in deep water. Transportation facilities, collection systems, and pipelines must follow the production platforms. These facilities are vulnerable to extreme natural phenomena such as hurricanes and earthquakes, as Hurricanes Katrina and Rita demonstrated in the Gulf of Mexico in 2005.

Technical failure. Technical failure is a term that refers to interruptions or accidents arising from human or natural causes in the operation of an element of the energy infrastructure. As this infrastructure becomes larger, more complex, and dispersed, such events are inevitable. There are many recent examples: oil spills from pipelines and tankers, transmission grid failures, and accidents in refineries. Unquestionably, safety and reliable operation will receive greater attention by both industry and regulators. Efforts to improve safety and reliable operation for normal commercial operation will benefit efforts to protect the energy infrastructure from natural disasters and hostile threats.

Terrorist, insurgency, and hostile-state threats to the energy infrastructure are likely to grow.[22] Because much of the energy infrastructure is located in remote areas or in areas such as the Middle East that are politically unstable, it is reasonable to expect an increased number of attacks. In February 2006, for example, terrorists made an abortive attack on the 600,000 barrel per day Abqaiq oil processing center in Saudi Arabia. In September 2006, terrorists believed to have connections with Al Qaeda simultaneously attacked a refinery and an oil storage depot in Yemen.

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22 The distinction between terrorist and counterinsurgency threats is blurred, but there are many examples: Chechnya, Colombia, Sudan, Angola, Nigeria, and Iraq are prominent among them.

It is not only oil and gas facilities that are vulnerable, but also tankers, port facilities, offshore production platforms, pipelines, power plants (especially nuclear power stations), and electricity transformation and transmission networks. And what about the ships that transport nuclear fuel and separated plutonium around the world? The reason that the energy infrastructure is an attractive target to terrorists is that these targets are "soft," that is, easily destroyed or incapacitated by a cyber attack that penetrates the SCADA (Supervisory Control and Data Acquisition) computer systems that do real-time monitoring and control of plant and equipment. The destruction of such targets can cause tremendous disruption and economic loss without large loss of life—a characteristic that can be very attractive to organized terrorist groups that seek to achieve political objectives and wish to avoid acts that invite more extreme retaliation.

These vulnerabilities—natural, technical, and from terrorists and other groups—give rise to security concerns that are receiving greater attention from both industry and governments.

Civilian responses of Trilateral countries. Trilateral countries are likely to pay considerably greater attention in the future than in the past to the vulnerability of the energy infrastructure, and they will adopt measures that better protect key facilities and plant operations from both natural disaster and terrorist attack. While it is not possible to guarantee absolute security from an attack, it is possible to take steps that will make this infrastructure more secure and raise the cost of a successful attack. Such protection is expensive, however, and arriving at a reasonable level will require cooperation between industry and government. Energy firms, especially those with international operations, should expect to spend more time on emergency preparedness planning: evaluating the vulnerability of their facilities and operations to natural disasters and terrorist attack and making investments in systems and procedures for protection.

Effective warning and defense systems will require international cooperation. For example, consider that LNG requires a liquefaction facility, an LNG tanker, and a re-gasification facility that spans two countries and open ocean transport. This points to what Trilateral countries should do:

- Establish international standards for the siting, construction, and operation of facilities;

- Exchange best practices information on energy infrastructure operations;
- Undertake joint operations to improve infrastructure protection, especially customs and port security; and
- Practice and exercise defenses and recovery.

Role of military forces. It is worth noting that deployed military forces help protect energy infrastructure. Military cooperation often offers a practical means of technical information exchange and joint planning and exercises in, for example, port security, air traffic control, and telecommunications. In general, cooperation between the military forces of Trilateral countries and the military forces of MRH countries, when it occurs, encourages professionalism and hence more responsible conduct by local military. There are additional, more central, connections between military force deployment and economic security.

The most obvious example is the role the U.S. Navy plays in keeping sea lanes safe for international shipping. Most nations recognize and welcome the function that the U.S. Navy plays in maintaining open seas. However, China and perhaps other nations will worry about the capability of the U.S. Navy to block tankers and other shipping entering or leaving Chinese ports, which may encourage China to begin the lengthy, expensive, and potentially risky process of developing a bluewater navy capability.

Most fundamentally, deployed military forces, if used wisely, can contribute to regional political stability. As the experience of the U.S. military intervention in Iraq indicates, military deployment does not automatically lead to stability; intervention can bring unexpected and costly consequences. Nevertheless, Trilateral countries, facing many decades of dependence on imported oil and gas, should consider how deployed military forces and their operations should be used in a manner that contributes to the objective of maintaining stable supply. For example, some will argue that the U.S. military should maintain a significant force deployment in both the Middle East and East Asia because this presence contributes to regional stability and thus will be generally welcomed by governments in the region. Forward-deployed military forces advance the U.S. interests of maintaining stability in oil-producing regions and countering terrorism and proliferation.

Global Warming

Global warming is a different kind of foreign policy issue. It does not have the direct national security implication, for example, of war in the Persian Gulf. But global warming is arguably, along with global poverty, the issue that can most seriously affect the economic and social circumstances of future generations.

Although not all agree, the informed scientific consensus is that the consequences of global warming are likely to be very damaging if anthropogenic emissions of greenhouse gases continue on their present course and are not reduced.[23] I have followed the evolution of understanding about the implications of greenhouse gas emission for climate change since I was director of energy research in the U.S. Department of Energy in the 1970s. I believe that continued emission of greenhouse gases will cause an increase in global temperature, although the timing and amount of the increase is somewhat uncertain. The impact of the temperature increase on climate and the ability of economies and societies to respond (there will be winners and losers) is less sure. Global warming will occur. We should adopt policies now to reduce emissions—how stringent depends upon judgments about present and future costs. The longer the world waits to adopt carbon constraints, the more difficult and costly it will be for our economies to adapt.

It is mindless to deny the foreign policy implications of a situation where business-as-usual conduct by individual nations involves the common welfare of all. Moreover, the global warming issue divides Trilateral nations, especially the United States and Europe, as to what should be done. Global warming also divides OECD countries and the rapidly growing, large emerging economies over who should bear the cost of mitigation. This subject is sure to remain prominently on the international agenda in years ahead. If the United States or any other OECD country that is a large producer of greenhouse gas emissions is to retain a leadership role in other areas, it cannot just opt out of the global climate change policy process.

23 The leading international authority on global warming is the Intergovernmental Panel on Climate Change (IPCC). Much useful information is found on its Web site, www.ipcc.ch/.

Table 2. CO_2 Emissions by Region

Year	OECD	Non-OECD	Total
2003	3.59	3.4	6.83
2030	4.77	7.14	11.91

Source: *International Energy Outlook 2006* (Washington, D.C.: U.S. Department of Energy, Energy Information Administration, June 2006).

Outlook for Global CO_2 Emissions

There are many greenhouse gases,[24] but I will focus on carbon dioxide, CO_2, because this product of combustion from fossil fuels, especially coal, accounts for over 70 percent of all greenhouse gas emissions, of which about 40 percent is from coal combustion, primarily from electricity generation.

The anticipated growth in these CO_2 emissions is given in table 2.

During the period 2003–2030, the *International Energy Outlook 2006* reference case projects that the CO_2 emissions of OECD countries will grow by 1.1 percent per year, while non-OECD Asia will grow by 3.6 percent.[25]

Because of the considerable lag between emissions and atmospheric concentration response, even if the world reduced emissions today, it would be a long time before atmospheric concentrations stabilized. The Intergovernmental Panel on Climate Change (IPCC), under the auspices of the World Meteorological Organization (WMO) and the UN Environmental Program (UNEP), offers a striking illustration (figure 4) of this lag in the results of a model that compares an emissions trajectory that stabilizes CO_2 atmospheric concentrations at 550 parts per million (ppm), about twice the preindustrial levels; this concentration would result in a global average increase of about 2.2°C. This trajectory, although uncertain, should be compared with the model prediction of continual upward trend in temperature, if the world stabilized emissions at the year 2000 level.

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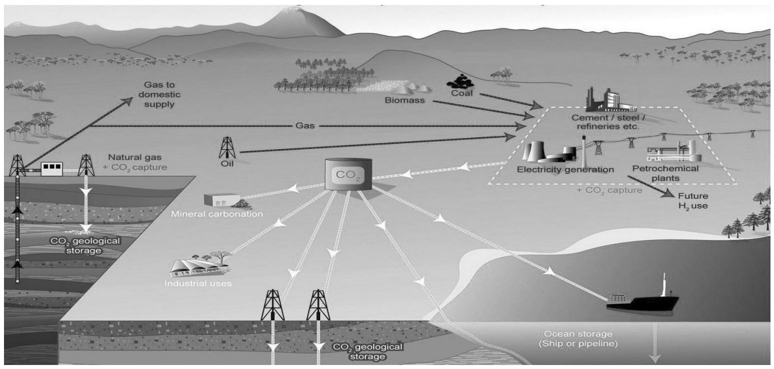
24 The principal greenhouse gases are: CO_2, carbon dioxide; CH_4, methane; N_2O, nitrous oxide; PFCs, perfluorocarbons; HFCs, hydrofluorocarbons; SF6, sulphur hexafluoride. Each compound has a different global warming potential.

25 *International Energy Outlook 2006,* 73, table 12.

Figure 8. Schematic Diagram of Possible CCS Systems



Source: *Climate Change 2001: Synthesis Report* (Geneva: Intergovernmental Panel on Climate Change, 2001).

Please remember that the relationship projected between the atmospheric concentration and global mean average temperature increase is based on a model that cannot be completely validated empirically. Thus, today researchers are addressing a more sophisticated question: What is the probability that the temperature increase will be greater or less than the 2.2°C predicted in the mode?

What would it take to reduce carbon emissions? At MIT, we have just completed a study, *The Future of Coal: Options for a Carbon Constrained World,*[26] that used the MIT Emissions Prediction and Policy Analysis (EPPA) model[27] to analyze the level of carbon emission reduction needed to stabilize world emissions by 2050. This is only a step toward the goal of stabilizing CO_2 atmospheric concentrations at 550 ppm. While emissions are sharply reduced compared with business-as-usual, further reductions would be required. The MIT EPPA model is a self-consistent description of economic adjustments that

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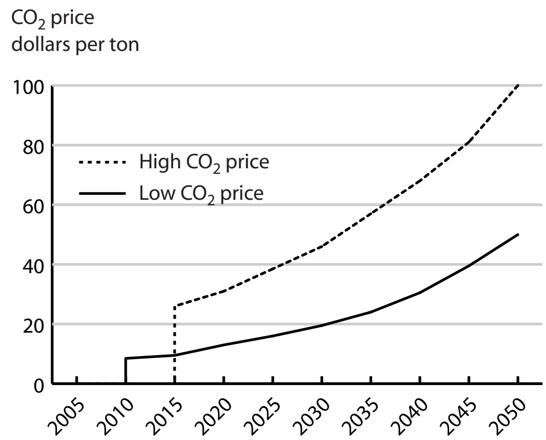
26 S. Ansolabehere et al.,*The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), http://web.mit.edu/coal/.

27 A description of the MIT Emissions Prediction and Policy Analysis (EPPA) model is found in Sergey Paltsev et al., *The MIT Emissions and Policy Analysis (EPPA) Model: Version 4,* Report no. 125 (Cambridge, Mass.: Joint Program on the Science and Policy of Climate Change, August 2005), http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt125.pdf.

Figure 5. Scenarios of Penalties on CO_2 Emissions, dollars per ton CO_2 in constant dollars



Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), 9, Fig 2.2, http://web.mit.edu/coal/.

occur over time by region and industrial sector, based on assumed policies, supply and demand curves for commodities, and technical characteristics of energy technologies.

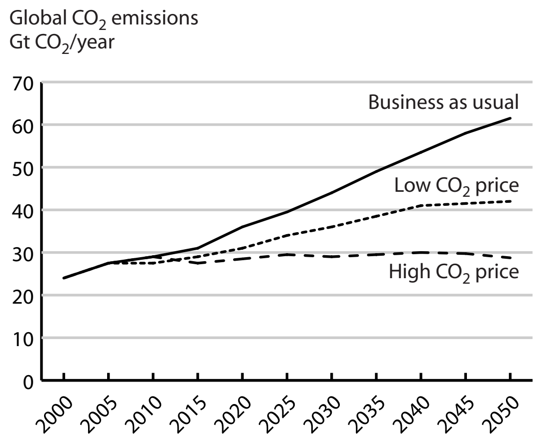
For the MIT *Future of Coal* study, the EPPA model was used to estimate the future effects of two carbon emission price penalty scenarios. This penalty or emissions price can be thought of as the result of a global cap-and-trade regime, a system of harmonized carbon taxes, or even a combination of price and regulatory measures that combine to impose marginal penalties on emissions. The result is presented in figure 5 for assumed real price penalties placed on CO_2 emissions.

If such a pattern of CO_2 emission penalties were adopted, global CO_2 emissions would be stabilized by mid-century (see figure 6).

The low CO_2 price case resembles the recommendation of the recent National Commission on Energy Policy;[28] the effect of this low-price scenario lags the high-price scenario by about twenty-five years.

28 *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* (Washington, D.C.: National Commission on Energy Policy, December 2004), www.energycommission.org/files/contentFiles/report_noninteractive_44566feaabc5d.pdf.

Figure 6. Global CO_2 Emissions under Alternative Policies with Universal, Simultaneous Participation, Limited Nuclear Expansion, and EPPA-Ref Gas Prices, $GtCO_2$/year

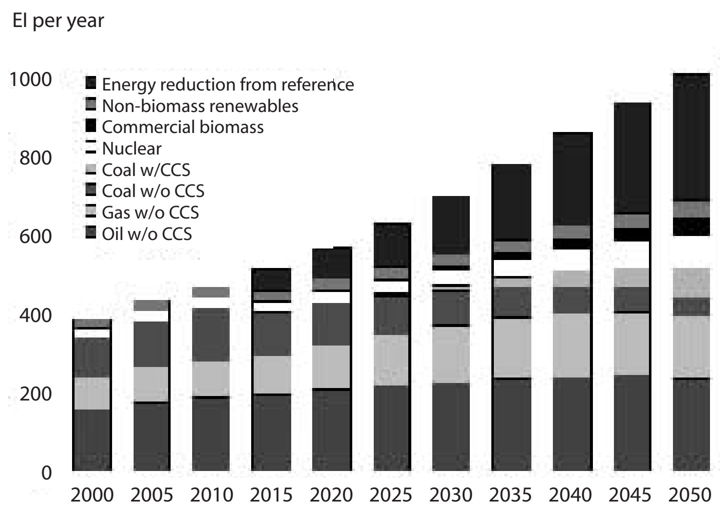


Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), 10, Fig 2.3, http://web.mit.edu/coal/.

This analysis shows that it is possible to stabilize global CO_2 emissions by mid-century. Emission reductions will occur because the global economy will respond to the higher price of carbon emissions in three ways: significant reduction in energy use through improved efficiency of energy use and lower demand; a switch to lower carbon-emitting alternatives; and adoption of new carbon-avoiding technologies. For example, in the EPPA model projections, nuclear power, to the extent it is available, will displace coal-fired electricity generation. The United States and the rest of the world will produce significant quantities of biofuels from biomass, about 20 million barrels of oil per day equivalent. Although not modeled, presumably if international carbon credits are traded, there will be an incentive to increase biomass production globally.

The adjustment of global primary energy consumption to higher carbon prices displayed as reductions from a reference case with no prices is given in figure 7 for the case of expanded worldwide nuclear deployment.

Figure 7. Global Primary Energy Consumption under High CO_2 Prices (expanded nuclear generation and EPPA-ref gas prices)



Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), 11, Fig 2.5, http://web.mit.edu/coal/.

Effect on Coal

Coal costs about $1 per million BTU compared with natural gas at about $8 per million BTU, and there are vast deposits of coal in large energy-consuming countries, notably Australia, China, India, Russia, and the United States. Each year, commitments are made that inevitably result in additional future annual emissions of CO_2. For example, China is building more than one large coal (1000 MWe) plant per week, each of which emits approximately 30,000 metric tons of CO_2 daily during the plant's forty-year life. As the use of coal for electricity generation expands significantly, the question arises, what is the future of coal if carbon constraints are applied compared with a business-as-usual world without constraints?

The MIT study, *Future of Coal,* estimates that at a carbon emission price of about $30 (in 2005 dollars) per ton of CO_2, coal combustion to produce electricity with CCS is economic. A snapshot at mid-century shows the positive impact on increased coal use and reduced CO_2 emissions from CCS if the technology is available when a carbon price is

Table 3. Exajoules of Coal Use (EJ) and Global CO_2 Emissions (Gt/yr), 2000 and 2050, with and without carbon capture and storage

	Present course		Limited nuclear		Expanded nuclear	
Coal use	**2000**	**2050**	**With CCS**	**Without CCS**	**With CCS**	**Without CCS**
Global	100	448	161	116	121	78
United States	24	58	40	28	25	13
China	27	88	39	24	31	17
CO_2 emissions: global	24	62	28	32	26	29
CO_2 emissions from coal	9	32	5	9	3	6

Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), xi, Table 1, http://web.mit.edu/coal/.

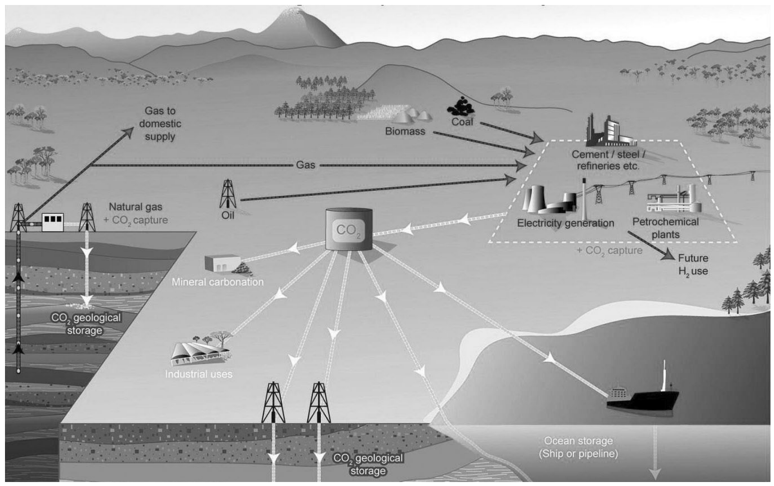
Notes: Assumes universal, simultaneous participation, high CO_2 prices, and EPPA-ref gas prices. CCS = carbon capture and storage.

imposed (table 3). In 2050, the availability of CCS means that coal use increases more than 80 percent if a high carbon price is imposed, and total CO_2 emissions are reduced more than 10 percent. Under this assumed carbon emission price scenario, moreover, the carbon capture penetration increases rapidly after 2050.

Thus, demonstrating the feasibility of CCS is important for establishing a technical option for CO_2 emission reduction in the future should serious carbon emission control measures be adopted. Today, the leading technologies for coal combustion with CO_2 capture are the integrated coal gasification combined cycle, favored in the United States, and the oxygen-fired, ultra-supercritical, pulverized-coal combustion, favored in Europe. With a CCS charge, the cost of electricity at the bus bar is increased about 50 percent, resulting in an increase in retail electricity cost of about 25 percent.

Because no coal plants currently operate with carbon capture, it is too early to pick a technology “winner,” although many do so; moreover, coal type is an important factor in the technology choice. The production of synthetic liquids and gas from oil and shale discussed in the previous section could also involve CO_2 capture in an emission control regime.

Figure 8. Schematic Diagram of Possible CCS Systems



Source: *Climate Change 2001: Synthesis Report* (Geneva: Intergovernmental Panel on Climate Change, 2001).

Status of Sequestration

Technical descriptions of CO_2 sequestration can be found in the IPCC study, *Carbon Dioxide Capture and Storage,*[29] and the MIT study, *Future of Coal.*[30] A CO_2 sequestration system that operates worldwide will have enormous scale—transporting and injecting volumes of CO_2 greatly in excess of the natural gas produced worldwide. Figure 8 indicates the complexity of the process.

The requirements for successfully demonstrating the option of carbon sequestration are three:

1. Integrated operation of capture, transportation, and injection of CO_2 at a storage site;
2. Operation at the scale of at least 1 million tons of CO_2 per year, including a system for measurement, monitoring, and verification; and

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29 Bert Metz et al., eds., *IPCC Special Report on Carbon Dioxide Capture and Storage* (New York: Cambridge University Press, 2005), www.ipcc.ch/activity/srccs/SRCCS.pdf.

30 Ansolabehere et al., *The Future of Coal.*

3. Establishment of an institutional and regulatory framework that addresses criteria for site selection, injection, monitoring, and operating standards, including assignment of liability provisions for industry and government extending to the end of the life of the storage site; such a framework is essential to establish public acceptance of sequestration, and allowance must be made for differing regulatory practices in different political jurisdictions.

The three major CO_2 sequestration projects[31] currently under way in Sleipner, Norway; Weyburn, Saskatchewan, Canada; and in Salah, Algeria, do not meet these requirements. A number of projects in various stages of planning anticipate integrating CO_2 capture and sequestration. In Germany, Vattenfall is undertaking a program with EU support for operation of an integrated Oxy pulverized coal (lignite) plant with CO_2 capture by 2015.[32] Each of these projects has been designed for a different purpose, and although valuable information has and will be learned, the projects do not satisfy the three requirements needed to establish carbon capture as an acceptable technical, economic, and political option. The annual project cost of each integrated carbon capture and demonstration project should be about $50 million per year.

Five or six integrated sequestration projects should be immediately undertaken to demonstrate that CO_2 sequestration is a credible carbon emission mitigation option. This is a central recommendation of the MIT coal study and it certainly is a program that should be possible for Trilateral countries to accomplish individually and cooperatively. Even the current U.S. administration, which does not believe that carbon emission control is needed, should support projects to establish that the sequestration option is available, if needed, in the future.

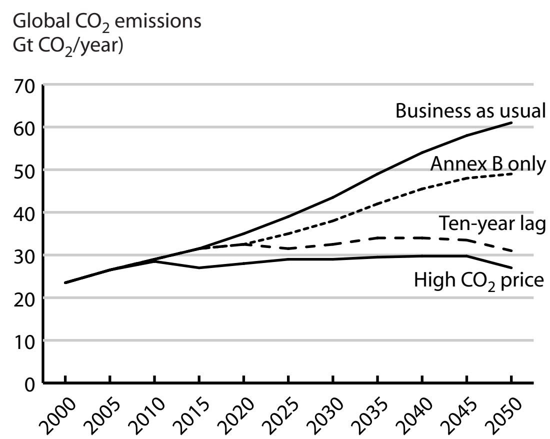
How can convergence between developed and developing economies be achieved? The foregoing discussion assumes that there is universal compliance in a carbon control regime. However, the 1994 United Nations Framework Convention on Climate Change[33] and the 1997

31 A brief description of these projects can be found at the MIT Carbon Capture and Sequestration Technologies Web site, http://sequestration.mit.edu/index.html.

32 A description of the Vattenfall plant is found at http://www2.vattenfall.com/www/co2_en/co2_en/index.jsp.

33 Background information and relevant documents can be found at the Web site of the United Nations Framework Convention on Climate Change, http://unfccc.int.

Figure 9. Global CO_2 Emissions under BAU and Alternative Scenarios for Non-Annex B Accession to the High CO_2 Price Path

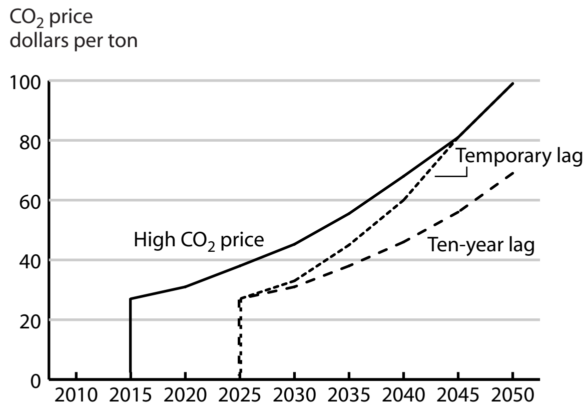


Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), 14, Fig 2.7, http://web.mit.edu/coal/.

Kyoto Protocol include obligations of only thirty-five developed economies (Annex I countries) to limit their emissions to amounts listed in Annex B. Fifteen EU countries agreed to an aggregate reduction of −8 percent of 1990 emissions by 2008/2012; Japan and Canada agreed to −6 percent, with the United States indicating that it would not ratify the protocol and thus would not seek to achieve its previously stated target of −5 percent reduction.

The Kyoto Protocol does not include any obligation on the part of the large, rapidly growing emerging economies to restrict greenhouse gas emissions. This difference in obligations between developed and developing economies reflects a basic difference in interests: developed economies have been responsible for the bulk of past emissions into the atmosphere and wish to constrain future emissions; developing economies, which have not been large emitters in the past and have much lower emissions per capita, argue that in fairness they should have the opportunity of a period of time for economic growth without restrictions on their greenhouse gas emissions. The trouble is that if developing economies do not constrain their emissions, global warming will result regardless of the action taken by the developed economies, as indicated in figure 9 above.

Figure 10. Scenarios of Penalties on CO_2 Emissions: High Price for Annex B Nations and Two Patterns of Participation by Non-Annex B Parties



Source: S. Ansolabehere et al., *The Future of Coal: Options for a Carbon Constrained World* (Cambridge: Massachusetts Institute of Technology, 2007), 13, Fig 2.6, http://web.mit.edu/coal/.

The trend is clear: if only Annex B countries constrain emissions and developing countries do not, stabilization of global CO_2 emissions by 2050 is not possible. Of course, it is not necessary for developed and developing economies to adopt exactly the same schedule of restrictions on greenhouse gas and CO_2 emissions. The figure also indicates the consequences of a hypothetical ten-year lag in developing countries accepting a high carbon price of emissions. If developing economies adopt a CO_2 price with ten-year lag, stabilization is possible, depending upon the precise price trajectory. As indicated in figure 10, the lag could be temporary, in which case, during a convergence period, developing economies would experience a higher rate of growth of the real price increase than developed economies. If the lag were permanent, developing economies would have a permanent comparative advantage in energy costs.

How might convergence be achieved? Several possible approaches are discussed as a means of achieving convergence.[34] One possibility is to build on the Kyoto process and pursue continued dialogue in the regularly scheduled Conference of Parties, taking advantage of provisions in the Kyoto Protocol, such as "Clean Development Mechanisms," "Joint Implementation," emissions trading, and expanding CO_2 sinks by reforestation. However, we should not expect that continued dialogue based on the Kyoto Protocol will necessarily lead to progress on the underlying equity issue on how global emission constraint cost might be shared between developed and developing economies. Many believe a new and broader framework is needed. At the Trilateral Commission's 2006 North American regional meeting in Cambridge, Massachusetts, Harvard professor Robert Stavins presented a thorough discussion of the architecture needed for a post-Kyoto era.[35] The study, *Beyond Kyoto,* sponsored by the Pew Center on Global Climate Change, is also relevant.[36]

In 2005, Sir Nicolas Stern prepared a review of the economics of climate change for the Chancellor of the Exchequer of the United Kingdom.[37] The Stern review is a comprehensive economic analysis, and it eloquently calls for immediate and collective action. There are several

34 My discussion of convergence addresses the need to harmonize carbon emission constraint policies between developed and emerging economies. For these policies to be effective, if adopted in a developing country, the emerging economy must have a sufficiently developed market economy so that the economic behavioral response assumed for a developed economy—that is, demand response to price changes—operates. If the market structure is not sufficiently developed, as might be the case in China, compliance will not necessarily result in the emission reductions predicted by the conventional models that are calibrated on the response observed in developed economies.

35 Robert N. Stavins, "Climate Change: Technology and Politics" (paper delivered to the Trilateral Commission's 2006 North American regional meeting), www.trilateral.org/NAGp/regmtgs/06pdf_folder/Stavins.pdf. See also Robert N. Stavins and Sheila M. Olmstead, "An International Policy Architecture for the Post-Kyoto Era," *American Economic Review Papers and Proceedings* 96, no. 2 (May 2006): 35–38; Robert N. Stavins, "Forging a More Effective Global Climate Treaty," *Environment Magazine,* December 2004, 24.

36 Joseph E. Aldy et al., *Beyond Kyoto: Advancing the International Effort against Climate Change* (Arlington Va.: Pew Center on Global Climate Change, December 2003), www.pewclimate.org/docUploads/Beyond%20Kyoto%2Epdf.

37 Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2006), www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

technical critiques of the Stern review analysis. For example, William Nordhaus observes that the Stern review's economic analysis adoption of a near zero social discount rate is the crucial determinant of the very high carbon charge the review recommends.[38] I find its discussion of how higher prices will result in the introduction of carbo-avoiding technologies overly optimistic.[39]

Part IV of the Stern review enumerates the advantages and disadvantages of different price-based instruments for influencing carbon emissions. One can imagine how these might be applied to achieve a new international understanding about how convergence should be reached between Annex I (developed) and non-Annex I (emerging economies) on sharing carbon constraint costs. One possible mechanism would be to grant emerging economies initial emission allowances in excess of emission levels in a baseline year.[40] In a global cap-and-trade system, developed countries could purchase emission rights from developing countries, thus effectively providing a transfer of resources to meet the costs associated with carbon emission constraints.

There are several reasons why this approach is unlikely to work. Significant assistance in meeting compliance cost would involve a huge wealth transfer that most developed nations would be reluctant to consider. Emerging economies have given no indication as to what might be an acceptable level of compensation for constraints, and developed countries have given no indication of what consideration might be offered to emerging economies that place constraints on emission profiles. Moreover, it is not clear that all the large emerging economies have the capacity to operate a cap-and-trade system that requires, among other things, a mechanism for internal allocation of emission allowances, a reliable national energy data collection system, and inspection and enforcement mechanisms.

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38 William Nordhaus, "The *Stern Review* on the Economics Of Climate Change," November 17, 2006, www.econ.yale.edu/~nordhaus/homepage/SternReviewD2.pdf.

39 Stern, *Economics of Climate Change,* chap. 16, note 28.

40 Many have proposed such an approach; see, for example, Richard B. Stewart and Jonathan B. Wiener, "Practical Climate Change Policy," *Issues in Science and Technology* (Winter 2003), www.issues.org/20.2/stewart.html. See also a book by the same authors, *Reconstructing Climate Policy: Beyond Kyoto* (Washington, D.C.: American Enterprise Institute, 2003).

Part VI of the Stern review addresses how collective action might be achieved. The review notes that even if developed countries reduce their emissions by 60 percent from 1990 levels by 2050, developing economies would need to reduce emissions by 25 percent from the 1990 level to achieve stable emissions that eventually would lead to atmospheric CO_2 equivalent concentrations of 550 ppm. If developed countries reduced their emissions by 90 percent, then developing economies could increase their emissions by 50 percent to achieve the same outcome.[41]

An alternative approach that has been suggested is that Annex 1 countries might impose a tax on imports from non-Annex 1 countries as a way of encouraging these countries to adopt carbon constraints. Presumably, the level of the import tax is set by some combination of environmental external cost attributed to greenhouse gas emissions and from the difference in energy costs in Annex 1 and non-Annex 1 countries. The press reports that Prime Minister Dominique de Villepin of France has made such a proposal.[42] I hope such an approach is not adopted. A coercive approach to this convergence problem is unlikely to be practical or to influence the nations that are the most obvious targets—the United States and China.

A realistic appraisal is that we are making no progress in achieving such ambitious goals, and that it is inconceivable that any significant progress will be made if the United States, currently the world's largest emitter of greenhouse gases, is not an active participant in the process. From my perspective, the greatest political danger in the United States is not continued adherence to the position of the current administration that global warming does not require collective action. Rather, the danger is that the Congress promptly passes a weakened version of the McCain-Lieberman bill, which puts in place a relatively restricted cap-and-trade system with an opt-out feature permitting open-ended

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41 Stern, *The Economics of Climate Change*, 459, Figures 21.1 and 21.2.

42 "French Plan Would Tax Imports from Non-Signers of Kyoto Pact," *New York Times* (Reuters), November 14, 2006; see also the Web site of the prime minister: www.premierministre.gouv.fr/en/information/latest_news_97/sustainable_development_unveiling_the_57272.htmlministre.gouv.fr/en/information/latest_news_97/sustainable_development_unveiling_the_57272.html.

purchase of allowances at a low price.[43] Initial constraints of this sort are insufficient to cause any change and are considered as a first step toward meaningful constraints. The risk is that Congress agrees to adopt the low-cost first step, believes the problem to be "solved," and delays serious deliberation about more stringent controls.

Consequences and Choices

My view is that four changes are needed to make progress on the global warming issue.

First, the United States must adopt a carbon emission control policy.

Second, an agreed framework is needed between developed economies and large emerging economies about how the costs of carbon emission control will be shared.

Third, the leading technology for controlling greenhouse gas emissions is CCS.[44] Trilateral countries should urgently launch five to six large CCS projections around the world in order to demonstrate the technical feasibility and public acceptance of carbon sequestration.

Fourth, there should be expanded use of nuclear power; this is discussed in the next section.

Because there has been so little progress on reaching a workable approach to controlling greenhouse gas emissions, the question naturally arises: What happens if countries take no action?

First is to hope that the effects of greenhouse gases on climate occur sufficiently slowly that there is time for world societies and economies to adapt to the change gradually and without great suffering and disruption. And there is always the possibility of an unexpected tech-

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43 For an analysis of the McCain-Lieberman bill, S-139, see William A. Pizer and Raymond J. Kopp, "Summary and Analysis of McCain-Lieberman—'Climate Stewardship Act of 2003'; S.139, introduced 01/09/03," Resources for the Future, Washington, D.C., January 28, 2003, www.rff.org/rff/Core/Research_Topics/Air/McCainLieberman/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=4452. The Energy Information Administration, Office of Integrated Analysis and Forecasting, has posted an analysis of the original version of the 2003 McCain-Lieberman bill, "Analysis of S.139, the Climate Stewardship Act of 2003: Highlights and Summary," June 2003, www.eia.doe.gov/oiaf/servicerpt/ml/pdf/summary.pdf.

44 For a review, see Metz et al., eds., *IPCC Special Report on Carbon Dioxide Capture and Storage.*

nical innovation that will greatly alleviate the problem. Thomas Schelling is a respected and knowledgeable proponent of this view.[45]

The second possibility is that a disruptive and costly climate event will occur and that this event will convince the public and political leaders that action is urgently needed. I am skeptical that crisis is a good catalyst for adopting wise policy. Some suggestions for possible crisis responses reinforce my conviction.

If a climate crisis occurs, the mitigation approach may not work because it may then be too late for these measures to take effect. Attention will turn to the possibility of "geotechnical" solutions, which refer to active human intervention intended to reverse the effects on global climate of the emission of greenhouse gases from human activity. Recently, an increasing number of experts have been suggesting that more serious consideration be given to geotechnical solutions because emission mitigation does not seem to be acceptable. One prominent person to advance recently this possibility was Nobel Laureate Paul J. Crutzen.[46]

I do not wish to test the patience of those who are not technically knowledgeable but nevertheless experienced and thus properly cautious about accepting big risks. So I simply list some of the geotechnical measures that are under discussion to give an impression of the active measures that may be possible to counterbalance the global warming effects of greenhouse gas emissions:[47]

- Adding aerosols to the stratosphere (sulfate, soot, dust, metallic particles);
- Placing balloons or mirrors in the stratosphere;

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45 Thomas C. Schelling, "Some Economics of Global Warming," *American Economic Review* 82, 1 (1992); "The Cost of Combating Global Warming," *Foreign Affairs,* November–December 1997; "What Makes Greenhouse Sense," *Foreign Affairs,* May–June 2002.

46 Paul J. Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" *Climatic Change* 77, no. 3–4 (August 2006): 211–220.

47 A number of these measure were discussed at an informal meeting at a NASA, Ames Research Center–Carnegie Institution workshop, November 18–19, 2006. For background, see D. W. Keith, "Geoengineering the Climate: History and Prospect," *Annual Review of Energy and the Environment* 25 (2000): 245–284.

- Making deserts more reflective;
- Modifying the ocean albedo;
- Fertilizing the ocean to increase CO_2 uptake; and
- Creating high-altitude nuclear explosions to induce a nuclear "spring."

These measures do not have the benign character of reforestation. Instead they involve human intervention at a large scale in order to correct the global climate system for the perturbation in the global climate system caused by anthropomorphic greenhouse gas emissions. It is a very tall technical order to demonstrate control over such intervention with the level of confidence demanded by responsible public action. The geotechnical intervention option's greatest value is that its prospects should encourage Trilateral countries to redouble their efforts to seek a mitigation solution.

Nuclear Energy

Concern with global warming and the increasing price of natural gas has understandably stimulated interest in expanded use of nuclear power. In the short run, nuclear power can substitute for coal and natural gas–fired electricity generation; in the long run, the possibility exists of using electricity to a greater extent in both individual and mass transportation systems.

At present, nuclear power generation accounts for about 16 percent of the world's electricity production; most of the installed nuclear capacity is in the United States, Europe, and East Asia. But nuclear power use faces considerable challenges: capital costs must go down; progress must be made on waste management; and best safety practices in design, construction, and operation must be assured. Most important, for security, any expansion of commercial nuclear power must not be an avenue for countries to move toward or acquire a weapons capability. The example of Iran is the most immediate.

The nonproliferation issue is especially critical because projections of growth of electricity consumption in emerging economies are two to three times the rate projected for the developed world. We are speaking about countries such as Indonesia, Turkey, Egypt, Taiwan, and South Korea that might raise some concerns, but also countries such as Chile, Argentina, and Brazil.

The 2003 MIT study, *The Future of Nuclear Power,*[48] suggested that a tripling of global nuclear generating capacity, from about 300 GWe[49] to 1,000 GWe by mid-century, might be feasible. However, nuclear power in the developing world would grow from about 10 GWe in 2000 to 300 GWe in 2050. The objective of Trilateral countries should be to assure that these countries have access to the benefits of power generation without providing them with the technologies that invite the spread of nuclear weapons.

The most potentially dangerous technologies are enrichment (at the front end of the fuel cycle) and reprocessing (at the back end of the fuel cycle); see figure 11. Enrichment lifts the percentage of the fissile uranium-235 from 0.7 percent in natural abundance to about 3 percent for commercial fuel. Enrichment technologies such as centrifuges can be used to increase the percentage of U-235 to weapons grade. Reprocessing refers to chemical separation of the actinides, uranium and plutonium, from the fission production in the spent fuel. The plutonium isotope, Pu-239, formed during reactor operation by neutron absorption of the plentiful uranium isotope, U-238, is directly bomb usable.

Trilateral countries acting through the Group of Eight (G-8) have acknowledged the need to adopt new mechanisms to improve the proliferation resistance of commercial nuclear power. The objective is to adopt new proliferation-resistant mechanisms that would make it more difficult to use nuclear power as a path to acquiring nuclear weapons capability, thereby reducing the risk of proliferation.

It is unrealistic to believe, however, that adopting new mechanisms is a guarantee that a state will not be able to acquire nuclear weapons. Iran, a Nuclear Non-Proliferation Treaty (NPT) signatory, is an example of a state that appears to be seeking both nuclear power and nuclear weapons technology. States that seek a nuclear weapons capability do so because of their perception of their security interests, and when they do so, if history is any guide, such states will pursue a clandestine route to acquiring the strategic nuclear material needed for the bomb. Adopting new mechanisms to safeguard nuclear power from diversion seeks to preserve this distinction.

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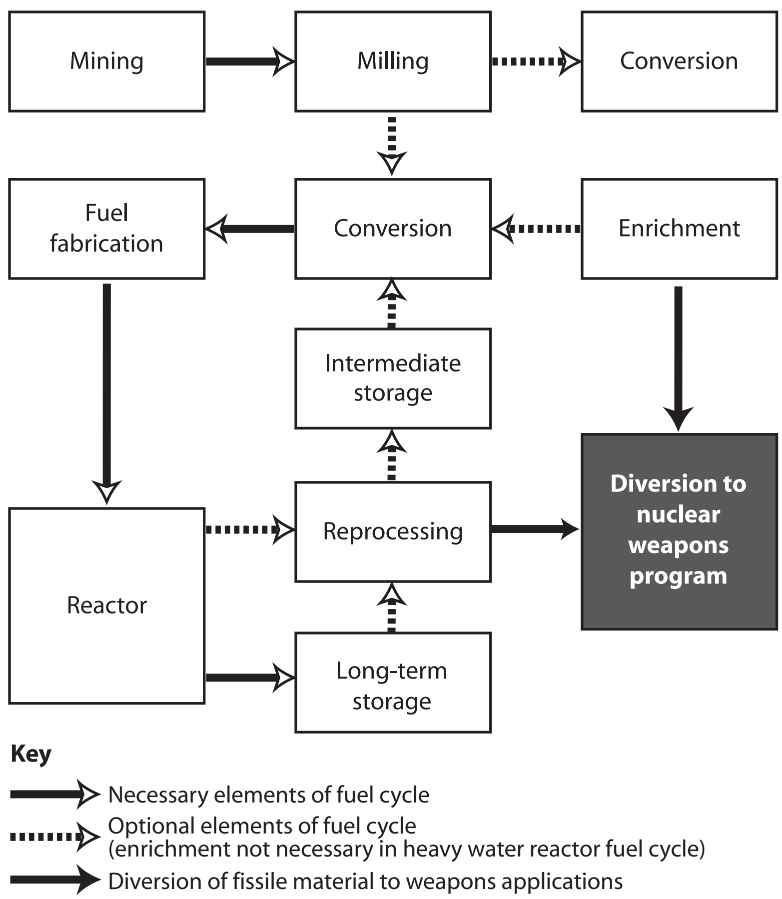
48 S. Ansolabehere et al., *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge: Massachusetts Institute of Technology, 2003), http://web.mit.edu/nuclearpower/.

49 A large nuclear power station has a capacity of about 1,000 megawatts electric output (MWe), which equals 1 gigawatt (GWe).

Figure 11. The Nuclear Fuel Cycle



Source: "The Nuclear Fuel Cycle," Center for Nonproliferation Studies, Monterey, Calif., http://cns.miis.edu/research/wmdme/flow/iran/index.htm#1.

Trilateral countries and the G-8 have adopted a common approach to strengthening proliferation safeguards in anticipation of a possible expansion in nuclear power use. The G-8 has taken a series of measures beginning in its meeting in 2004 at Sea Island, Georgia, then in 2005 at Gleneagles, Scotland, and culminating in 2006 in St. Petersburg, Russia, where the G-8 announced its support of new mechanisms for nuclear supplier states to supply fuel cycle services to states that want to use nuclear power.[50]

Here is how it might work:[51]

Countries that do not possess uranium enrichment and plutonium reprocessing facilities would agree not to obtain any such facilities and related technologies and materials. In exchange, they would receive guaranteed cradle-to-grave fuel services under an agreement that was financially attractive and signed by all those countries in a position to provide them. The International Atomic Energy Agency (IAEA) would sign also and would apply safeguards to any such fuel cycle activities covered by the agreement in addition to its traditional safeguard activities with regard to the reactors in the recipient states. The idea is to make costly indigenous fuel cycle facilities less attractive than reliable fuel cycle services from a few nuclear supplier states.

To be effective, the arrangement would need to include a guarantee to the recipient country at least for enrichment services. It is not likely that a recipient country would make an investment in a reactor without an international guarantee that a quarrelsome U.S. Congress could not abruptly terminate commercial contracts for enriched fuel, for example. The guarantee would be strengthened by an international enrichment "bank" or "reserve," operated perhaps by the IAEA. In a remarkable display of public support for such a security initiative, former U.S. senator Sam Nunn, the cochair of the U.S.-based Nuclear Threat Initiative, announced that Warren Buffett had pledged $50 million toward a total of $150 million for a low enriched uranium stockpile owned and operated by the IAEA.[52]

This is a new approach that amounts to an important revision of the terms of President Dwight D. Eisenhower's 1953 "atoms for peace" deal between nuclear have and have-not states. The implicit deal in "atoms for peace" was that nuclear weapon states would provide ac-

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50 "Global Energy Security," G-8 Summit 2006, St. Petersburg, Russia, July 16, 2006, item no. 31, http://en.g8russia.ru/docs/11.html.

51 John Deutch, Arnold Kanter, Ernest Moniz, and Daniel Poneman, "Making the World Safe for Nuclear Energy," *Survival* 46, no. 4 (Winter 2004–2005).

52 See former senator and NTI cochair Sam Nunn's speech and NTI's press release, September 19, 2006: www.nti.org/c_press/speech_Nunn_IAEAFuelBank_FINALlogo.pdf; http://nti.org/c_press/release_IAEA_fuelbank_091906.pdf.

cess to technology and nuclear material to non-weapon states in exchange for the recipient non-weapon state agreeing to forgo nuclear weapons. The proposed conditions for today's deal are more stringent: recipient states get access to technology and nuclear power reactors but not to the more sensitive parts of the fuel cycle. These fuel cycle services—enrichment and reprocessing—would come from a restricted number of nuclear supplier states. The universe of nuclear supplier states remains to be defined; presumably, supplier states initially would consist of the nuclear weapon states plus some others, for example, Germany, Japan.

Of course, a good policy idea may be a long way from a functioning policy. As yet there is no concrete example of such an arrangement. At one point, the Iranian Bushehr-1 reactor, constructed by the Russians, seemed to be a good model. The Russians would "lease" the fuel, that is, they would provide enriched fuel and take back the depleted fuel for reprocessing, or disposal, or both. However, the unwillingness of the Iranians to suspend their enrichment activities at Natanz has for the time being halted any progress on Trilateral support for Iran's nuclear program.[53]

Brazil's plan for construction of a $210 million enrichment facility at Resende (a project run by the Brazilian navy) presented a second opportunity to achieve this new fuel cycle arrangement.[54] The United States chose to acquiesce to the Brazilian enrichment program and to object to the Iranian enrichment program on the grounds that the latter was dangerous and the former was not. I do not believe a proliferation policy will be workable in the long run unless the rules have international scope and can be consistently and objectively applied. The Brazilian decision to proceed with its domestic enrichment plant is a setback to the proposed G-8 policy to internationalize fuel cycle services.

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53 For a description of Iran's nuclear activity, see "Iran Profile," NTI, Washington, D.C., http://nti.org/e_research/profiles/Iran/index.html.

54 For background, see "Brazil Profile," NTI, Washington, D.C., http://nti.org/e_research/profiles/Brazil/index.html; see also Sharon Squassoni and David Fite, "Brazil as a Litmus Test: Resende and Restrictions on Uranium Enrichment," *Arms Control Today*, October 2005, www.armscontrol.org/act/2005_10/Oct-Brazil.asp.

A third event was the December 18, 2006, signing of the U.S.-India Peaceful Atomic Energy Cooperation Act.[55] While the strengthening of the political relationship between the United States and India has much to recommend it, this action is not positive on nonproliferation grounds because it serves to legitimize a country that is not a NPT signatory; India is instead an "undeclared" nuclear weapons state that does not permit IAEA inspections of its nuclear facilities.

Practical realization of the new policy calls urgently for one example that works. An important, infrequently acknowledged barrier is that few countries are willing to accept the return of spent fuel. Russia will take back fuel of Russian origin; the situation with regard to the European Union and France, in particular, is less clear. I say with some confidence that the United States will not be willing to accept returned spent fuel until its waste management program is in better health.

I conclude with some emphasis that all Trilateral countries should support the G-8 nonproliferation initiatives that seek to provide assurances of fresh fuel and spent fuel management to states that agree not to pursue enrichment and reprocessing programs.

Advanced Fuel Cycle Development

In parallel with the nonproliferation initiative, the G-8 announced at St. Petersburg, Russia, its support for the development of "innovative nuclear power systems."[56] Several members of the G-8, notably France, Japan, and Russia, are eager to support the U.S. initiative, the Global Nuclear Energy Partnership (GNEP), to develop a new advanced fuel cycle.[57] The GNEP advanced fuel cycle will include a new separation

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55 For a description of the provisions of the act, see the fact sheet from the Office of the White House Press Secretary, December 16, 2006, www.whitehouse.gov/news/releases/2006/12/20061218-2.html.

56 "Global Energy Security," G-8 Summit 2006, item no. 29, states:

> The development of innovative nuclear power systems is considered an important element for efficient and safe nuclear energy development. In this respect, we acknowledge the efforts made in the complementary frameworks of the INPRO project and the Generation IV International Forum. Until advanced systems are in place, appropriate interim solutions could be pursued to address back-end fuel cycle issues in accordance with national choices and nonproliferation objectives.

57 A description of the GNEP can be found on the U.S. Department of Energy Web site, www.gnep.energy.gov/.

process that is somewhat more proliferation resistant (because the plutonium and uranium are not separated into separate streams as occurs in the conventional PUREX separation process) and a new family of reactors, Generation IV, which are capable of burning the long-lived radioactive actinide isotopes.

The GNEP intends that the United States return to a "closed" nuclear fuel cycle, where plutonium is recycled and mixed with uranium to form mixed oxide fuel to produce power in the reactor. The United States presently uses an "open" fuel cycle, where the spent fuel from reactors is not recycled but discarded in a geologic repository with its long-lived actinide isotopes. The alleged advantages of the closed cycle are: (1) it makes the waste management task easier because the absence of long-lived isotopes means the nuclear waste's radioactivity decays sooner (after several hundred years, rather than several tens of thousand years); (2) the uranium resource base is extended manyfold because of the breeding and reuse of plutonium in power reactors; and (3) the new system can be made proliferation resistant.

The United States had a long debate in the 1970s about the relative merits of a closed versus open fuel cycle. President Ford cancelled plans for reprocessing of commercial spent fuel in 1975. President Carter placed the country on the open fuel cycle path, canceled projects related to the closed fuel cycle—for example, the Clinch River breeder reactor—and argued in international forums such as the International Fuel Cycle Evaluation study that the open fuel cycle, as then configured, presented unacceptable risks in international commerce because it made bomb-usable separated plutonium widely available. The U.S. view influenced the attitudes of Trilateral countries about the proliferation risks of fuel cycle exports but did not convince Trilateral countries to abandon the closed cycle indigenously. For example, France is the world leader in the development and operation of commercial nuclear fuel reprocessing at La Hague. Japan and the United Kingdom have had mixed results in their reprocessing efforts.

Here I want to stress that it is by no means clear that the United States will proceed with the GNEP. There is strong criticism of this approach, which I share, and for the program to succeed, it will require decades of work and the support of many administrations.[58] The new GNEP architecture does not offer a clear advantage for waste disposal because the long-term environmental benefits of removing actinides from the waste must be balanced against the near-term risks of operating complex reprocessing and fuel fabrication plants. All agree that the closed cycle will be more expensive (although not a large percentage of the total cost of electricity) than the open cycle for many decades until, if, and when there is sufficient deployment of conventional nuclear power plants to drive up the cost of natural uranium ore to the point where reprocessing and fabrication of spent fuel is economic.

The strongest objection concerns the nonproliferation consequences of this strategy. At the same time that the G-8 is attempting to convince other countries not to deploy indigenous reprocessing technology, it announced that the G-8 should urgently pursue such technology for themselves. Other countries, such as Iran, Brazil, Turkey, South Korea, and Taiwan, might well wonder whether they are being asked to give up an important technology. The alleged improved proliferation resistance of the advanced reprocessing technologies is a fantasy. Supplier states such as France, Russia, and the United States are not proliferation risks. Essentially, other nations will not have a nuclear power industry of sufficient size to justify the large and expensive fuel cycle envisioned by the GNEP. In any case, if a country decided to divert material, relatively modest additional processing would be needed to recover pure plutonium.

My conclusion is that a major United States or G-8 effort to develop an advanced closed fuel cycle, rather than meeting the objective of "deploying advanced, proliferation resistant nuclear energy systems that avoid separation of pure plutonium and make it as difficult as possible to misuse or divert nuclear materials to weapons,"[59] will in fact derail the prospects for an orderly expansion of nuclear power throughout the world at a time when there are few alternatives to further emissions of CO_2 from electricity generating technologies.

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58 For a thorough critique, see Richard K. Lester, "New Nukes," *Issues in Science and Technology,* Summer 2006, www.issues.org/issues/22.4/index.html; see also John Deutch and Ernest J. Moniz, "A Plan for Nuclear Waste," *Washington Post,* January 30, 2006, Sec. A.

59 Dennis Spurgeon, assistant secretary for nuclear energy, U.S. Department of Energy, "Assurances of Nuclear Supply and Nonproliferation" (speech at IAEA, Vienna, Austria, September 19, 2006), http://energy.gov/news/4173.htm.

In time, if use of nuclear power significantly expands around the world, it may be justifiable to adopt a closed fuel cycle. But, at present, pursuing the GNEP risks making that future less likely. As Matthew Bunn so aptly puts it, the GNEP substitutes the U.S. message in place since 1975, "we believe reprocessing is unnecessary and we are not doing it," with the message "reprocessing is essential for the future of nuclear power, but we will keep the technology away from all but a few states."[60]

The political dynamic in the United States that makes the GNEP attractive is the false hope that a closed cycle will lead to a waste disposal solution. The U.S. Congress is weary of cost overruns and delays in constructing the waste repository at Yucca Mountain, Nevada. Congress has the false hope that a closed cycle will be easier to accomplish and politically more acceptable. But opposition will mount quickly. Proliferation risk is a powerful public issue, and the GNEP supporters do not have an extensive political base compared with, for example, the farm interests that support corn-based gasohol. The GNEP will cost billions of incremental research and development dollars that many will judge could be better spent on other energy programs, especially on developing technologies that encourage greater energy efficiency. In sum, the future of the GNEP in the United States is highly dubious.

Encouraging Nuclear Power

What should Trilateral countries do to encourage nuclear power? First, work out effective procedures to assure international guarantees for nuclear fuel supplies; second, encourage supplier states, such as Russia, that are willing to take back spent fuel; third, strengthen the IAEA inspection regime, in particular by encouraging adherence to the IAEA "additional protocol,"[61] which gives the IAEA greater authority to chal-

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60 Matthew Bunn, "Assessing the Benefits, Costs, and Risks of Near-Term Reprocessing and Alternatives" (testimony before the Subcommittee on Energy and Water Appropriations, U.S. Senate, September 14, 2006), http://bcsia.ksg.harvard.edu/BCSIA_content/documents/bunn_gnep_testimony.pdf.

61 For additional information, see "Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards," Document INFCIRC/540, International Atomic Energy Agency, Vienna, Austria, September 1997, www.iaea.org/Publications/Documents/Infcircs/1998/infcirc540corrected.pdf.

lenge inspections of undeclared facilities in NPT party states; and fourth, establish a consortium among nuclear supplier nations with existing technologies and financial instruments able to offer developing nations nuclear power at reasonable cost and without proliferation risk. This amounts to an open cycle strategy for nuclear exports for at least the next several decades.

Of course, a research program on advanced nuclear fuel cycles should go forward. But these research activities should be limited to laboratory-scale research on new separation technologies, design, analysis, and simulation of new fuel cycle systems as well as experiments to obtain engineering data. Large demonstration facilities and any suggestion of near-term deployment of a closed fuel cycle system should be deferred for the foreseeable future.

Conclusions

I have discussed four energy security issues. Here are summary conclusions about what should be done about each:

1. To mitigate the effects of oil and gas import dependence, we must begin the process of a transition away from a petroleum-based economy and recognize the inevitable dependence on petroleum until that transition is accomplished.
2. Reducing the growing vulnerability of the energy infrastructure calls for greater cooperation for Trilateral countries and others involved in international energy markets.
3. Both developed and developing economies need to curb CO_2 and other greenhouse gas emissions to avoid the adverse consequences of climate change or face the prospect of active engineering of the globe's climate.
4. The need for encouraging expanded use of nuclear power means that new measures must be adopted to reduce the increase in proliferation risk that would result from the spread of dangerous fuel cycle services—enrichment and reprocessing.

We justifiably should be concerned that the world is not making sufficient progress on these issues. One possibility is that the world will continue to muddle along and make the inevitable adjustments. Another possibility is that a severe crisis will change the attitude of the public and its leaders about what needs to be done. I am uncomfortable with either of these possibilities because I believe each will involve much higher economic and social cost than is necessary. A much better option is to manage the significant social, technical, and economic aspects of the energy transitions the world will undergo. I hope that the Trilateral Commission, both as an organization and as individuals, will strive to make progress on these energy issues in the years ahead, appreciating that energy and security issues are not divisible, and I look forward to a promising assessment at future meetings.