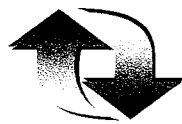


ISSUE 11



Are Biofuels Responsible for Rising Food Prices?

YES: Donald Mitchell, from "A Note on Rising Food Prices," The World Bank Development Prospects Group (July 2008)

NO: Keith Kline, Virginia H. Dale, Russell Lee, and Paul Leiby, from "In Defense of Biofuels, Done Right," *Issues in Science and Technology* (Spring 2009)

ISSUE SUMMARY

YES: Donald Mitchell argues that although many factors contributed to the increase in internationally traded food prices from January 2002 to June 2008, the most important single factor was the large increase in biofuels production from grains and oilseeds in the U.S. and EU.

NO: Keith Kline, Virginia H. Dale, Russell Lee, and Paul Leiby argue that the impact of biofuels production on food prices is much less than alarmists claim. There would be greater impact if biofuels development focused on converting biowastes and fast-growing trees and grasses into fuels.

The threat of global warming has spurred a great deal of interest in finding new sources of energy that do not add to the amount of carbon dioxide in the air. Among other things, this has meant a search for alternatives to fossil fuels, which modern civilization uses to generate electricity, heat homes, and power transportation. Finding alternatives for electricity generation or home heating is easier than finding alternatives for transportation (which relies on oil, refined into gasoline and diesel oil). In addition, the transportation infrastructure, consisting of refineries, pipelines, tank trucks, gas stations, and an immense number of cars and trucks that will be on the road for many years, is well designed for handling liquid fuels. It is not surprising that industry and government would like to find non-fossil liquid fuels for cars and trucks (as well as ships and airplanes).

There are many suitably flammable liquids. Among them are the so-called biofuels or renewable fuels, plant oils and alcohols that can be distilled from plant sugars. According to Daniel M. Kammen, "The Rise of Renewable Energy," *Scientific American* (September 2006), the chief biofuel in the U.S. so far

is ethanol, distilled from corn and blended with gasoline. Production is subsidized with \$2 billion of federal funds, and "when all the inputs and outputs were correctly factored in, we found that ethanol" contains about 25 percent more energy (to be used when it is burned as fuel) than was used to produce it. At least one study says the "net energy" is actually less than the energy used to produce ethanol from corn; see Dan Charles, "Corn-Based Ethanol Flunks Key Test," *Science* (May 1, 2009). If other sources, such as cellulose-rich switchgrass or cornstalks, can be used, the "net energy" is much better. However, generating ethanol requires first converting cellulose to fermentable sugars, which is so far an expensive process (although many people are working on making the process cheaper; see e.g., Jennifer Chu, "Reinventing Cellulosic Ethanol Production," *Technology Review* online, June 10, 2009, <http://www.technologyreview.com/energy/22774/?nid=2091>), and George W. Huber and Bruce E. Dale, "Grassoline at the Pump," *Scientific American* (July 2009). A significant additional concern is the amount of land needed for growing crops to be turned into biofuels; in a world where hunger is widespread, this means land is taken out of food production. If additional land is cleared to grow biofuel crops, this must mean loss of forests and wildlife habitat, increased erosion, and other environmental problems. See "Ethanol: Energy Well Spent, A Survey of Studies Published Since 1990," Natural Resources Defense Council and Climate Solutions (February 2006) (<http://www.nrdc.org/air/transportation/ethanol/ethanol.pdf>).

Under the Energy Policy Act of 2005, the U.S. Environmental Protection Agency (EPA) requires that gasoline sold in the United States contain a minimum volume of renewable fuel. Under the Renewable Fuel Program (also known as the Renewable Fuel Standard Program, or RFS Program), that volume will increase over the years, reaching 36 billion gallons by 2022. According to the EPA (<http://www.epa.gov/otaq/renewablefuels/>), "the RFS program was developed in collaboration with refiners, renewable fuel producers, and many other stakeholders." However, some think it is premature and even dangerous to put so much emphasis on biofuels. William Tucker, "Food Riots Made in the USA," *The Weekly Standard* (April 28, 2008), blames the food riots seen in many countries in 2008 on price increases due in large part to the shift in agricultural production from food grains to biofuels crops.

In the following selections, Donald Mitchell argues that although many factors contributed to the increase in internationally traded food prices from January 2002 to June 2008, the most important single factor—accounting for as much as 70 percent of the rise in food prices—was the large increase in biofuels production from grains and oilseeds in the U.S. and EU. Without these increases, global wheat and maize stocks would not have declined appreciably, and price increases due to other factors would have been moderate. Keith Kline, Virginia H. Dale, Russell Lee, and Paul Leiby argue that the impact of biofuels production on food prices is much less than alarmists claim. If biofuels development focused on converting biowastes and fast-growing trees and grasses into fuels, the overall impact would be even better, with a host of benefits in reduced fossil fuel use and greenhouse gas emissions, increased employment, enhanced wildlife habitat, improved soil and water quality, and more stable land use.

A Note on Rising Food Prices

I. Introduction

Internationally traded food commodities prices have increased sharply since 2002 and especially since late-2006, and prices of major staples, such as grains and oilseeds, have doubled in just the past two years. Rising prices have caused food riots in several countries and led to policy actions such as the banning of grain and other food exports by a number of countries and tariff reductions on imported foods in others. The policy actions reflect the concern of governments about the impact of food price increases on the poor in developing countries who, on average, spend half of their household incomes on food. This paper examines how internationally traded food commodities prices (maize, wheat, rice, soybeans, etc.) have changed, and analyzes the factors contributing to these increases. In particular, it looks at the contribution of biofuels production to food price increases. In this paper biofuels refer to ethanol and biodiesel.

II. The Rise in Global Food Prices

The IMF's index of internationally traded food commodities prices increased 130 percent from January 2002 to June 2008 and 56 percent from January 2007 to June 2008. Prior to that, food commodities prices had been relatively stable after reaching lows in 2000 and 2001 following the Asia financial crisis. The low levels of global grain stocks had been identified as a cause for concern in a number of fora and the risk of higher food prices was highlighted in a recent World Bank publication and online.

The increase in food commodities prices was led by grains which began sustained price increases in 2005 despite a record global crop in the 2004/05 crop year that was 10.2 percent larger than the average of the three previous years and a near record crop in 2005/06 that was still 8.9 percent larger. Global stocks of grain increased in 2004/05 but declined in 2005/06 as demand increased more than production. From January 2005 until June 2008, maize prices almost tripled, wheat prices increased 127 percent and rice prices increased 170 percent. The increase in grain prices was followed by increases in fats & oils prices in mid-2006, and that also followed a record 2004/05

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global oilseed crop that was 13 percent larger than in the previous year and an even larger crop in 2005/06. Fats & oils prices have shown similar increases to grains, with palm oil prices up 200 percent from January 2005 until June 2008, soybean oil prices up 192 percent, and other vegetable oils prices increasing by similar amounts. Other foods prices (sugar, citrus, bananas, shrimp and meats) increased 48 percent from January 2005 to June 2008.

III. Recent Estimates of the Contribution of Biofuels Production to Food Prices

Estimates of the contribution of biofuels production to food price increases are difficult, if not impossible to compare. Estimates can differ widely due to different time periods considered, different prices (export, import, wholesale, retail) considered, and different coverage of food products. . . .

[But] [d]espite all the differences in approach, many studies recognize biofuels production as a major driver of food prices. The USDA's chief economist in testimony before the Joint Economic Committee of Congress on May 1, attributed much of the increase in farm prices of maize and soybeans to biofuels production. The IMF estimated that the increased demand for biofuels accounted for 70 percent of the increase in maize prices and 40 percent of the increase in soybean. Collins used a mathematical simulation to estimate that about 60 percent of the increase in maize prices from 2006 to 2008 may have been due to the increase in maize used in ethanol. Rosegrant, et al., using a general equilibrium model, calculated the long-term impact on weighted cereal prices of the acceleration in biofuel production from 2000 to 2007 to be 30 percent in real terms. Maize prices were estimated to have increased 39 percent in real terms, wheat prices increased 22 percent and rice prices increased 21 percent. During this period, the U.S. CPI increased by 20.4 percent, which would imply nominal prices increases of 47, 26, and 25, respectively, for maize, wheat and rice prices. This is the same order of magnitude as was calculated with the World Bank's linkages model. Differences in the estimates of the impact of biofuels on the price index of all food depend largely on how broadly the food basket is defined and what is assumed about the interaction between prices of maize and vegetable oils (directly influenced by demand for biofuels) to prices of other crops such as rice through substitution on the supply or demand side. For example, the Council of Economic Advisors estimated that retail food prices increased only about 3 percent over the past 12 months due to ethanol production, in part because they only considered the impact of maize prices, directly and indirectly, on retail prices.

Many other potential drivers of the escalating food prices are mentioned in discussions, but there are few quantitative estimates of their impacts. For example, a recent USDA report attributed the increase in world market prices for major food commodities such as grains and vegetable oils to many factors including biofuels as well as other factors including the declining dollar, rising energy prices, increasing agricultural costs of production, growing foreign exchange holdings by major food-importing countries, and recent policies by some exporting countries to mitigate their own food-price inflation.

IV. Estimates of Factors Contributing to the Rise in Food Commodities Prices

There are a number of factors that have contributed to the rise in food prices. Among these are the increase in energy prices and the related increases in prices of fertilizer and chemicals, which are either produced from energy or are heavy users of energy in their production process. This has increased the cost of production, which ultimately gets reflected in higher food prices. Higher energy prices have also increased the cost of transportation, and increased the incentive to produce biofuels and encouraged policy support for biofuels production. The increase in biofuels production has not only increased demand for food commodities, but also led to large land use changes which reduced supplies of wheat and crops that compete with food commodities used for biofuels. Drought in Australia in 2006 and 2007 and poor crops in Europe in 2007 added to the grain and oilseed price increases, and rapid import demand increases for oilseeds by China to feed its growing livestock and poultry industry contributed to oilseed price increases. Other factors, including the decline of the dollar, and the increased investment in commodities by institutional investors to hedge against inflation and diversify portfolios may have also contributed to the price increases. The remainder of this section will examine these factors.

High energy prices have contributed about 15–20 percent to higher U.S. food commodities production and transport costs. Production costs per acre for U.S. corn, soybeans and wheat increased 32.3, 25.6 and 31.4 percent, respectively, from 2002 to 2007, according to the USDA's cost-of-production surveys and forecasts. However, yield increases during this period reduced the per bushel cost increases to 17.0, 24.1 and 6.7 percent, respectively. The contribution of the energy-intensive components of production costs—fertilizer, chemicals, fuel, lubricants and electricity—were 13.4 percent for corn, 6.7 percent for soybeans and 9.4 percent for wheat per bushel. The production-weighted average increase in the cost of production due to these energy-intensive inputs for these crops was 11.5 percent between 2002 and 2007. In addition to the increase in production costs, transport costs also increased due to higher fuel costs and the margin between domestic and export prices reflect this cost. However, these margins also include handling and other charges, such as insurance, which increase with crop prices. The margin for corn between central Illinois cash and the Gulf Ports barge increased from \$0.36 to \$0.72 per bushel for an increase of 15.5 percent, while the margin between Kansas City and the Gulf Ports wheat increased only \$1 per metric ton. An export weighted average of these prices suggests that transport costs could have added as much as 10.2 percent to the export prices of corn and wheat. Comparable data was not available for soybeans. Thus, the combined increase in production costs and transport costs for the major U.S. food commodities—corn, soybeans and wheat—was at most 21.7 percent, and this amount likely overstates the increase, because transport costs are not estimated separately. It therefore seems reasonable to conclude that higher energy and related costs increased export prices of major U.S. food commodities by about 15–20 percent between 2002 and 2007.

Increased biofuel production has increased the demand for food commodities. The use of maize for ethanol grew especially rapidly from 2004 to 2007 and used 70 percent of the increase in global maize production. In contrast, feed use of maize, which accounts for 65 percent of global maize use, grew by only 1.5 percent per year from 2004 to 2007 while ethanol use grew by 36 percent per year. The share of global feed use of total use declined in response to maize price rises from 69 to 64 percent from 2004 to 2007, and from 70 to 67 percent when the feed by-products from biofuel production are included in feed use.

The United States is the largest producer of ethanol from maize and is expected to use about 81 million tons for ethanol in the 2007/08 crop year. Canada, China, and the European Union used roughly an additional 5 million tons of maize for ethanol in 2007, bringing the total use of maize for ethanol to 86 million tons, which was about 11 percent of global maize production. The large use of maize for ethanol in the U.S. has important global implications, because the U.S. accounts for about one-third of global maize production and two-thirds of global exports and used 25 percent of its production for ethanol in 2007/08.

About 7 percent of global vegetable oil supplies were used for biodiesel production in 2007 and about one-third of the increase in consumption from 2004 to 2007 was due to biodiesel. The largest biodiesel producers were the European Union, the United States, Argentina, Australia, and Brazil, with a combined use of vegetable oils for biodiesel of about 8.6 million tons in 2007 compared with global vegetable oils production of 132 million tons according to the USDA (2008f). From 2004 to 2007, global consumption of vegetable oils for all uses increased by 20.8 million tons, with food use accounting for 80 percent of total use and 60 percent of the increase. Industrial uses of vegetable oils (which include biodiesel) grew by 15 percent per annum from 2004 to 2007, compared with 4.2 percent per annum for food use. The share of industrial use of total use rose from 14.4 percent in 2004 to 18.7 percent in 2007.

Imports of vegetable oils by the EU and U.S. have increased substantially, with the EU-27 increasing imports from 4.4 to 6.9 million tons from 2000 to 2007 and the U.S. increasing imports from 1.7 to 2.9 million tons. The large imports coincided with the increase in biodiesel production in the EU-27 from .45 billion gallons in 2004 to 1.9 billion gallons in 2007 and from .03 billion gallons in the U.S. in 2004 to an estimated .44 billion gallons in 2007.

Brazilian ethanol production from sugar cane has not contributed appreciably to the recent increase in food commodities prices, because Brazilian sugar cane production has increased rapidly and sugar exports have nearly tripled since 2000. Brazil uses approximately half of its sugar cane to produce ethanol for domestic consumption and exports and the other half to produce sugar. The increase in cane production has been large enough to allow sugar production to increase from 17.1 million tons in 2000 to 32.1 million tons in 2007 and exports to increase from 7.7 million tons to 20.6 million tons. Brazil's share of global sugar exports increased from 20 percent in 2000 to 40 percent in 2007, and that was sufficient to keep sugar price increases small

except for 2005 and early 2006 when Brazil and Thailand had poor crops due to drought.

The increases in biofuels production in the EU, U.S., and most other bio-fuel-producing countries have been driven by subsidies and mandates. The U.S. has a tax credit available to blenders of ethanol of \$0.51 per gallon and an import tariff of \$0.54 per gallon, as well as a biodiesel blenders tax credit of \$1.00 per gallon. The U.S. mandated 7.5 billion gallons of renewable fuels by 2012 in its 2005 legislation and raised the mandate to 15 billion gallons of ethanol from conventional sources (maize) by 2022 and 1.0 billion gallons of biodiesel by 2012 in energy legislation passed in late-2007. The new U.S. mandates will require ethanol production to more than double and biodiesel production to triple if they are met from domestic production. The EU has a specific tariff of €0.192/liter of ethanol (€0.727 or about \$1.10 per gallon) and an ad valorem duty of 6.5 percent on biodiesel. EU member states are permitted to exempt or reduce excise taxes on biofuels, and several EU member states have introduced mandatory blending requirements. Individual member states have also provided generous excise tax concessions without limit, and Germany for example, has provided tax exemptions of €0.4704/ (\$0.64) per liter of biodiesel and €0.6545 (\$0.88) per liter of ethanol prior to new legislation in 2006. These strong incentives and mandates encouraged the rapid expansion of biofuels in both the EU and U.S.

The EU began to rapidly expand biodiesel production after the EU directive on biofuels entered into effect in October 2001 stipulating that national measures must be taken by EU countries aimed at replacing 5.75 percent of all transport fossil fuels with biofuels by 2010. This led to an increase in biodiesel production from 0.28 billion gallons in 2001 to 1.78 billion gallons in 2007 (FAPRI 2008). Rapeseed was the primary feedstock, followed by soybean oil and sunflower oil. The combined use of vegetable oils for biodiesel was 6.1 million tons in 2007 compared with about 1.0 million tons in 2001.

The U.S. expanded its biodiesel production following legislation passed in 2004 which took effect in January 2005, providing an excise tax credit of US\$1.00 per gallon of biodiesel made from agricultural products. This contributed to an increase in biodiesel production in the U.S. from 0.03 billion gallons in 2005 to .44 billion gallons in 2007 and used 3.0 million tons of soybean oil and 0.3 million tons of other fats and oils. These two policies encouraged the rapid expansion of oilseeds production for biodiesel and contributed to the surge in vegetable oils prices, with annual average soybean oil prices rising from \$354/ton in 2001 to \$881 per ton in 2007. Monthly soybean oil prices rose to \$1,522/ton in June 2008. Since oilseeds are close substitutes and prices highly correlated, this led to similar increases in other oilseeds prices.

Land use changes due to expanded biofuel's feedstock production have been large and have led to reduced production of other crops. The U.S. expanded maize area 23 percent in 2007 in response to high maize prices and rapid demand growth for maize for ethanol production. This expansion resulted in a 16 percent decline in soybean area, which reduced soybean production and contributed to a 75 percent rise in soybean prices between April 2007 and April 2008.

While maize displaced soybeans in the U.S., other oilseeds displaced wheat in the EU and other wheat exporting countries. The expansion of biodiesel production in the EU diverted land from wheat and slowed the increase in wheat production, which would have otherwise kept wheat stocks higher. In response to the increased demand and rising prices for oilseeds, land planted to oilseeds increased, especially rapeseed and to a lesser extent sunflower. The increase was primarily in the countries that are also major wheat exporters such as Argentina, Canada, the EU, Russia, and Ukraine. Oilseeds and wheat are grown under similar climatic conditions and in similar areas and most of the expansion of rapeseed and sunflower displaced wheat or was on land that could have grown wheat. The 8 largest wheat exporting countries expanded area in rapeseed and sunflower by 36 percent (8.4 million hectares) between 2001 and 2007 while wheat area fell by 1.0 percent. The wheat production potential of this land was 26 million tons in 2007 based on average wheat yields in each country, and the cumulative wheat production potential of that land totaled 92 million tons from 2002 to 2007. To illustrate the impact of this land shift on wheat stocks, . . . [simulations show that] if the land planted to rapeseed and sunflower had been planted to wheat and if wheat stocks had increased by the same amounts . . . wheat stocks would have been almost as large in 2007 as in 2001 rather than lower by almost half.

Export bans and restrictions fueled the price increases by restricting access to supplies. A number of countries have imposed export restrictions or bans on grain exports to contain domestic price increases. These include Argentina, India, Kazakhstan, Pakistan, Ukraine, Russia, and Vietnam. . . . According to the USDA and the International Grains Council, there were no other important market developments at that time that could account for the subsequent rice price increases. The USDA had projected India to export 4.1 million tons in the month prior to the ban and that was revised to 3.4 million tons in the month following the ban. The ban on exports led to a steady increase in prices over the following weeks. While it is probably not correct to say that all of the price increases were due to the ban, it likely focused attention on the market fundamentals and the rise in wheat prices and caused market participants to reconsider their imports and exports.

Rice is not used for biofuels, but the increase in prices of other commodities contributed to the rapid rise in rice prices. Rice prices almost tripled from January to April 2008 despite little change in production or stocks. This increase was mostly in response to the surge in wheat prices in 2007 (up 88 percent from January to December) which raised concerns about the adequacy of global grain supplies and encouraged several countries to ban rice exports to protect consumers from international price increases, and caused others to increase imports.

Weather-related production shortfalls have been identified as a major factor underpinning world cereals prices, especially in Australia, U.S., EU, Canada, Russia, and Ukraine. The back-to-back droughts in Australia in 2006 and 2007 reduced grain exports by an average of 9.2 million tons per year compared with 2005, and poor crops in the EU and Ukraine reduced their exports by an additional 10 million tons in 2007. However, these declines were more

than offset by large crops in Argentina, Kazakhstan, Russia, and the U.S. Total grain exports from these countries in 2007 increased by about 22 million tons compared with 2006. Global grain production did decline by 1.3 percent in 2006, but it then increased 4.7 percent in 2007. Thus, the production shortfall in grains would not, by itself, have been a major contributor to the increase in grain prices. But when combined with large increases in biofuels production, land use changes, and stock declines it undoubtedly contributed to higher prices. The production shortfall was most significant in wheat, where global production declined 4.5 percent in 2006 and then increased only 2 percent in 2007. Global oilseed production rose 5.4 percent in 2006/07 and declined 3.4 percent in 2007/08.

Rapid income growth in developing countries has not led to large increases in global grain consumption and was not a major factor responsible for the large grain price increases. However, it has contributed to increased oilseed demand and higher oilseed prices as China increased soybean imports for its livestock and poultry industry. Both China and India have been net grain exporters since 2000, although exports have declined as consumption has increased. Global consumption of wheat and rice grew by only 0.8 and 1.0 percent per annum, respectively, from 2000 to 2007 while maize consumption grew by 2.1 percent (excluding the demand for biofuels in the U.S.). This was slower than demand growth during 1995–2000 when wheat, rice, and maize consumption increased by 1.4, 1.4, and 2.6 percent per annum, respectively.

Other factors, such as the decline of the dollar, contributed to food commodity price increases. . . .

Speculative and investor activity has also increased and could have contributed to food price increases. A reflection of this increased activity was the quadrupling of the number of wheat futures contracts traded on the Chicago Board of Trade from 2002 to 2006. However, the increase in futures contracts does not coincide closely with the increase in wheat prices, which raises doubts about the impact on prices. The impact on prices is hard to quantify and most studies do not find that such activity changes prices from the levels which would have prevailed without such activity, however, they may change the rate of adjustment to a new equilibrium when fundamental factors change.

Summary and Conclusions

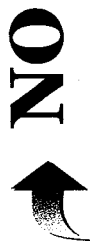
The increase in internationally traded food prices from January 2002 to June 2008 was caused by a confluence of factors, but the most important was the large increase in biofuels production from grains and oilseeds in the U.S. and EU. Without these increases, global wheat and maize stocks would not have declined appreciably, and price increases due to other factors would have been moderate. Land use changes in wheat exporting countries in response to increased plantings of oilseeds for biodiesel production limited expansion of wheat production that could have otherwise prevented the large declines in global wheat stocks and the resulting rise in wheat prices. The rapid rise in oilseed prices was caused mostly by demand for biodiesel production in response to incentives provided by policy changes in the EU beginning in 2001 and in the

U.S. beginning in 2004. The large increase in rice prices was largely a response to the increase in wheat prices rather than to changes in rice production or stocks, and was thus indirectly related to the increase in biofuels. Recent export bans on grains and speculative activity would probably not have occurred without the large price increases due to biofuels production because they were largely responses to rising prices. Higher energy and fertilizer prices would have still increased crop production costs by about 15–20 percentage points in the U.S. and lesser amounts in countries with less intensive production practices. The back-to-back droughts in Australia would not have had a large impact because they only reduced global grain exports by about 4 percent and other exporters would normally have been able to offset this loss. The decline of the dollar has contributed about 20 percentage points to the rise in dollar food prices.

Thus, the combination of higher energy prices and related increases in fertilizer prices and transport costs, and dollar weakness caused food prices to rise by about 35–40 percentage points from January 2002 until June 2008. These factors explain 25–30 percent of the total price increase, and most of the remaining 70–75 percent increase in food commodities prices was due to biofuels and the related consequences of low grain stocks, large land use shifts, speculative activity and export bans. It is difficult, if not impossible, to compare these estimates with estimates from other studies because of different methodologies, widely different time periods considered, different prices compared, and different food products examined, however, most other studies have also recognized biofuels production as a major factor driving food prices. The increase in grain consumption in developing countries has been moderate and did not lead to large price increases. Growth in global grain consumption (excluding biofuels) was only 1.7 percent per annum from 2000 to 2007, while yields grew by 1.3 percent and area grew by 0.4 percent, which would have kept global demand and supply roughly in balance. This was slower than growth during 1995–2000 when wheat, rice and maize consumption increased by 1.4, 1.4, and 2.6 percent per annum, respectively.

The large increases in biofuels production in the U.S. and EU were supported by subsidies, mandates, and tariffs on imports. Without these policies, biofuels production would have been lower, and food commodity price increases would have been smaller. Biofuels production from sugar cane in Brazil is lower-cost than biofuels production in the U.S. or EU and has not raised sugar prices significantly because sugar cane production has grown fast enough to meet both the demand for sugar and ethanol. Removing tariffs on ethanol imports in the U.S. and EU would allow more efficient producers such as Brazil and other developing countries, including many African countries, to produce ethanol profitably for export to meet the mandates in the U.S. and EU. Biofuels policies which subsidize production need to be reconsidered in light of their impact on food prices.

Keith Kline, Virginia H. Dale,
Russell Lee, and Paul Leiby



In Defense of Biofuels, Done Right

Biofuels have been getting bad press, not always for good reasons. Certainly important concerns have been raised, but preliminary studies have been misinterpreted as a definitive condemnation of biofuels. One recent magazine article, for example, illustrated what it called "Ethanol USA" with a photo of a car wreck in a corn field. In particular, many criticisms converge around grain-based biofuel, traditional farming practices, and claims of a causal link between U.S. land use and land-use changes elsewhere, including tropical deforestation.

Focusing only on such issues, however, distracts attention from a promising opportunity to invest in domestic energy production using biowastes, fast-growing trees, and grasses. When biofuel crops are grown in appropriate places and under sustainable conditions, they offer a host of benefits: reduced fossil fuel use; diversified fuel supplies; increased employment; decreased greenhouse gas emissions; enhanced habitat for wildlife; improved soil and water quality; and more stable global land use, thereby reducing pressure to clear new land.

Not only have many criticisms of biofuels been alarmist, many have been simply inaccurate. In 2007 and early 2008, for example, a bumper crop of media articles blamed sharply higher food prices worldwide on the production of biofuels, particularly ethanol from corn, in the United States. Subsequent studies, however, have shown that the increases in food prices were primarily due to many other interacting factors: increased demand in emerging economies, soaring energy prices, drought in food-exporting countries, cut-offs in grain exports by major suppliers, market-distorting subsidies, a tumbling U.S. dollar, and speculation in commodities markets.

Although ethanol production indeed contributes to higher corn prices, it is not a major factor in world food costs. The U.S. Department of Agriculture (USDA) calculated that biofuel production contributed only 5% of the 45% increase in global food costs that occurred between April 2007 and April 2008. A Texas A&M University study concluded that energy prices were the primary cause of food price increases, noting that between January 2006 and January 2008, the prices of fuel and fertilizer, both major inputs to agricultural production, increased by 37% and 45%, respectively. And the International Monetary Fund has documented that since their peak in July 2008, oil prices declined by 69% as of December 2008, and global food prices declined by

33% during the same period, while U.S. corn production has remained at 12 billion bushels a month, one-third of which is still used for ethanol production.

In another line of critique, some argue that the potential benefits of biofuel might be offset by indirect effects. But large uncertainties and postulations underlie the debate about the indirect land-use effects of biofuels on tropical deforestation, the critical implication being that use of U.S. farmland for energy crops necessarily causes new land-clearing elsewhere. Concerns are particularly strong about the loss of tropical forests and natural grasslands. The basic argument is that biofuel production in the United States sets in motion a necessary scenario of deforestation.

According to this argument, if U.S. farm production is used for fuel instead of food, food prices rise and farmers in developing countries respond by growing more food. This response requires clearing new land and burning native vegetation and, hence, releasing carbon. This "induced deforestation" hypothesis is based on questionable data and modeling assumptions about available land and yields, rather than on empirical evidence. The argument assumes that the supply of previously cleared land is inelastic (that is, agricultural land for expansion is unavailable without new deforestation). It also assumes that agricultural commodity prices are a major driving force behind deforestation and that yields decline with expansion. The calculations for carbon emissions assume that land in a stable, natural state is suddenly converted to agriculture as a result of biofuels. Finally, the assertions assume that it is possible to measure with some precision the areas that will be cleared in response to these price signals.

A review of the issues reveals, however, that these assumptions about the availability of land, the role of biofuels in causing deforestation, and the ability to relate crop prices to areas of land clearance are unsound. Among our findings:

First, sufficient suitably productive land is available for multiple uses, including the production of biofuels. Assertions that U.S. biofuel production will cause large indirect land-use changes rely on limited data sets and unverified assumptions about global land cover and land use. Calculations of land-use change begin by assuming that global land falls into discrete classes suitable for agriculture—cropland, pastures and grasslands, and forests—and results depend on estimates of the extent, use, and productivity of these lands, as well as presumed future interactions among land-use classes. But several major organizations, including the Food and Agriculture Organization (FAO), a primary data clearinghouse, have documented significant inconsistencies surrounding global land-cover estimates. For example, the three most recent FAO Forest Resource Assessments, for periods ending in 1990, 2000, and 2005, provide estimates of the world's total forest cover in 1990 that vary by as much as 470 million acres, or 21% of the original estimate.

Cropland data face similar discrepancies, and even more challenging issues arise when pasture areas are considered. Estimates for land used for crop production range from 3.8 billion acres (calculated by the FAO) to 9 billion acres (calculated by the Millennium Ecosystem Assessment, an international effort spearheaded by the United Nations). In a recent study attempting to

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reconcile cropland use circa 2000, scientists at the University of Wisconsin-Madison and McGill University estimated that there were 3.7 billion acres of cropland, of which 3.2 billion were actively cropped or harvested. Land-use studies consistently acknowledge serious data limitations and uncertainties, noting that a majority of global crop lands are constantly shifting the location of cultivation, leaving at any time large areas fallow or idle that may not be captured in statistics. Estimates of idle croplands, prone to confusion with pasture and grassland, range from 520 million acres to 4.9 billion acres globally. The differences illustrate one of many uncertainties that hamper global land-use change calculations. To put these numbers in perspective, USDA has estimated that in 2007, about 21 million acres were used worldwide to produce biofuel feedstocks, an area that would occupy somewhere between 0.4% and 4% of the world's estimated idle cropland.

Diverse studies of global land cover and potential productivity suggest that anywhere from 600 million to more than 7 billion additional acres of underutilized rural lands are available for expanding rain-fed crop production around the world, after excluding the 4 billion acres of cropland currently in use, as well as the world's supply of closed forests, nature reserves, and urban lands. Hence, on a global scale, land per se is not an immediate limitation for agriculture and biofuels.

In the United States, the federal government, through the multiagency Biomass Research and Development Initiative (BRDI), has examined the land and market implications of reaching the nation's biofuel target, which calls for producing 36 billion gallons by 2022. BRDI estimated that a slight net reduction in total U.S. active cropland area would result by 2022 in most scenarios, when compared with a scenario developed from USDA's so-called "baseline" projections. BRDI also found that growing biofuel crops efficiently in the United States would require shifts in the intensity of use of about 5% of pasture lands to more intensive hay, forage, and bioenergy crops (25 million out of 456 million acres) in order to accommodate dedicated energy crops, along with using a combination of wastes, forest residues, and crop residues. BRDI's estimate assumes that the total area allocated to USDA's Conservation Reserve Program (CRP) remains constant at about 33 million acres but allows about 3 million acres of the CRP land on high-quality soils in the Midwest to be offset by new CRP additions in other regions. In practice, additional areas of former cropland that are now in the CRP could be managed for biofuel feedstock production in a way that maintains positive impacts on wildlife, water, and land conservation goals, but this option was not included among the scenarios considered.

Yields are important. They vary widely from place to place within the United States and around the world. USDA projects that corn yields will rise by 20 bushels per acre by 2017; this represents an increase in corn output equivalent to adding 12.5 million acres as compared with 2006, and over triple that area as compared with average yields in many less-developed nations. And there is the possibility that yields will increase more quickly than projected in the USDA baseline, as seed companies aim to exceed 200 bushels per acre by 2020. The potential to increase yields in developing countries offers

tremendous opportunities to improve welfare and expand production while reducing or maintaining the area harvested. These improvements are consistent with U.S. trends during the past half century showing agricultural output growth averaging 2% per year while cropland use fell by an average of 0.7% per year. Even without large yield increases, cropland requirements to meet biofuel production targets may not be nearly as great as assumed.

Concerns over induced deforestation are based on a theory of land displacement that is not supported by data. U.S. ethanol production shot up by more than 3 billion gallons (150%) between 2001 and 2006, and corn production increased 11%, while total U.S. harvested cropland fell by about 2% in the same period. Indeed, the harvested area for "coarse grains" fell by 4% as corn, with an average yield of 150 bushels per acre, replaced other feed grains such as sorghum (averaging 60 bushels per acre). Such statistics defy modeling projections by demonstrating an ability to supply feedstock to a burgeoning ethanol industry while simultaneously maintaining exports and using substantially less land. So although models may assume that increased use of U.S. land for biofuels will lead to more land being cleared for agriculture in other parts of the world, evidence is lacking to support those claims.

Second, there is little evidence that biofuels cause deforestation, and much evidence for alternative causes. Recent scientific papers that blame biofuels for deforestation are based on models that presume that new land conversion can be simulated as a predominantly market-driven choice. The models assume that land is a privately owned asset managed in response to global price signals within a stable rule-based economy—perhaps a reasonable assumption for developed nations.

However, this scenario is far from the reality in the smoke-filled frontier zones of deforestation in less-developed countries, where the models assume biofuel-induced land conversion takes place. The regions of the world that are experiencing first-time land conversion are characterized by market isolation, lawlessness, insecurity, instability, and lack of land tenure. And nearly all of the forests are publicly owned. Indeed, land-clearing is a key step in a long process of trying to stake a claim for eventual tenure. A cycle involving incremental degradation, repeated and extensive fires, and shifting small plots for subsistence tends to occur long before any consideration of crop choices influenced by global market prices.

The causes of deforestation have been extensively studied, and it is clear from the empirical evidence that forces other than biofuel use are responsible for the trends of increasing forest loss in the tropics. Numerous case studies document that the factors driving deforestation are a complex expression of cultural, technological, biophysical, political, economic, and demographic interactions. Solutions and measures to slow deforestation have also been analyzed and tested, and the results show that it is critical to improve governance, land tenure, incomes, and security to slow the pace of new land conversion in these frontier regions.

Selected studies based on interpretations of satellite imagery have been used to support the claims that U.S. biofuels induce deforestation in the Amazon, but satellite images cannot be used to determine causes of land-use

change. In practice, deforestation is a site-specific process. How it is perceived will vary greatly by site and also by the temporal and spatial lens through which it is observed. Cause-and-effect relationships are complex, and the many small changes that enable larger future conversion cannot be captured by satellite imagery. Although it is possible to classify an image to show that forest in one period changed to cropland in another, cataloguing changes in discrete classes over time does not explain why these changes occur. Most studies asserting that the production and use of biofuels cause tropical deforestation point to land cover at some point after large-scale forest degradation and clearing have taken place. But the key events leading to the primary conversion of forests often proceed for decades before they can be detected by satellite imagery. The imagery does not show how the forest was used to sustain livelihoods before conversion, nor the degrees of continual degradation that occurred over time before the classification changed. When remote sensing is supported by a ground-truth process, it typically attempts to narrow the uncertainties of land-cover classifications rather than research the history of occupation, prior and current use, and the forces behind the land-use decisions that led to the current land cover.

First-time conversion is enabled by political, as well as physical, access. Southeast Asia provides one example where forest conversion has been facilitated by political access, which can include such diverse things as government-sponsored development and colonization programs in previously undisturbed areas and the distribution of large timber and mineral concessions and land allotments to friends, families, and sponsors of people in power. Critics have raised valid concerns about high rates of deforestation in the region, and they often point an accusing finger at palm oil and biofuels.

Palm oil has been produced in the region since 1911, and plantation expansion boomed in the 1970s with growth rates of more than 20% per year. Biodiesel represents a tiny fraction of palm oil consumption. In 2008, less than 2% of crude palm oil output was processed for biofuel in Indonesia and Malaysia, the world's largest producers and exporters. Based on land-cover statistics alone, it is impossible to determine the degree of attribution that oil palm may share with other causes of forest conversion in Southeast Asia. What is clear is that oil palm is not the only factor and that palm plantations are established after a process of degradation and deforestation has transpired. Deforestation data may offer a tool for estimating the ceiling for attribution, however. In Indonesia, for example, 28.1 million hectares were deforested between 1990 and 2005, and oil palm expansion in those areas was estimated to be between 1.7 million and 3 million hectares, or between 6% and 10% of the forest loss, during the same period.

Initial clearing in the tropics is often driven more by waves of illegitimate land speculation than agricultural production. In many Latin American frontier zones, if there is native forest on the land, it is up for grabs, as there is no legal tenure of the land. The majority of land-clearing in the Amazon has been blamed on livestock because, in part, there is no alternative for classifying the recent clearings and, in part, because land holders must keep it "in

production" to maintain claims and avoid invasions. The result has been the frequent burning and the creation of extensive cattle ranches. For centuries, disenfranchised groups have been pushed into the forests and marginal lands where they do what they can to survive. This settlement process often included serving as low-cost labor to clear land for the next wave of better-connected colonists. Unless significant structural changes occur to remove or modify enabling factors, the forest-clearing that was occurring before this decade is expected to continue along predictable paths.

Testing the hypothesis that U.S. biofuel policy causes deforestation elsewhere depends on models that can incorporate the processes underlying initial land-use change. Current models attempt to predict future land-use change based on changes in commodity prices. As conceived thus far, the computational general equilibrium models designed for economic trade do not adequately incorporate the processes of land-use change. Although crop prices may influence short-term land-use decisions, they are not a dominant factor in global patterns of first-time conversion, the land-clearing of chief concern in relating biofuels to deforestation. The highest deforestation rates observed and estimated globally occurred in the 1990s. During that period, there was a surplus of commodities on world markets and consistently depressed prices.

Third, many studies omit the larger problem of widespread global mismanagement of land. The recent arguments focusing on the possible deforestation attributable to biofuels use idealized representations of crop and land markets, omitting what may be larger issues of concern. Clearly, the causes of global deforestation are complex and are not driven merely by a single crop market. Additionally, land mismanagement, involving both initial clearing and maintaining previously cleared land, is widespread and leads to a process of soil degradation and environmental damage that is especially prevalent in the frontier zones. Reports by the FAO and the Millennium Ecosystem Assessment describe the environmental consequences of repeated fires in these areas. Estimates of global burning vary annually, ranging from 490 million to 980 million acres per year between 2000 and 2004. The vast majority of fires in the tropics occur in Africa and the Amazon in what were previously cleared, nonforest lands. In a detailed study, the Amazon Institute of Environmental Research and Woods Hole Research Center found that 73% of burned area in the Amazon was on previously cleared land, and that was during the 1990s, when overall deforestation rates were high.

Fire is the cheapest and easiest tool supporting shifting subsistence cultivation. Repeated and extensive burning is a manifestation of the lack of tenure, lack of access to markets, and severe poverty in these areas. When people or communities have few or no assets to protect from fire and no incentive to invest in more sustainable production, they also have no reason to limit the extent of burning. The repeated fires modify ecosystem structure, penetrate ever deeper into forest margins, affect large areas of understory vegetation (which is not detected by remote sensing), and take an ever greater cumulative toll on soil quality and its ability to sequester carbon. Profitable biofuel markets, by contributing to improved incentives to grow cash crops, could reduce the use of fire and the pressures on the agricultural frontier. Biofuels

done right, with attention to best practices for sustained production, can make significant contributions to social and economic development as well as environmental protection.

Furthermore, current literature calculates the impacts from an assumed agricultural expansion by attributing the carbon emissions from clearing intact ecosystems to biofuels. If emission analyses consider empirical data reflecting the progressive degradation that occurs (often over decades) before and independently of agriculture market signals for land use, as well as changes in the frequency and extent of fire in areas that biofuels help bring into more stable market economies, then the resulting carbon emission estimates would be worlds apart.

Brazil provides a good case in point, because it holds the globe's largest remaining area of tropical forests, is the world's second-largest producer of biofuel (after the United States), and is the world's leading supplier of biofuel for global trade. Brazil also has relatively low production costs and a growing focus on environmental stewardship. As a matter of policy, the Brazilian government has supported the development of biofuels since launching a National Ethanol Program called Proálcool in 1975. Brazil's ethanol industry began its current phase of growth after Proálcool was phased out in 1999 and the government's role shifted from subsidies and regulations toward increased collaboration with the private sector in R&D. The government helps stabilize markets by supporting variable rates of blending ethanol with gasoline and planning for industry expansion, pipelines, ports, and logistics. The government also facilitates access to global markets; develops improved varieties of sugarcane, harvest equipment, and conversion; and supports improvements in environmental performance.

New sugarcane fields in Brazil nearly always replace pasture land or less valuable crops and are concentrated around production facilities in the developed southeastern region, far from the Amazon. Nearly all production is rain-fed and relies on low input rates of fertilizers and agrochemicals, as compared with other major crops. New projects are reviewed under the Brazilian legal framework of Environmental Impact Assessment and Environmental Licensing. Together, these policies have contributed to the restoration or protection of reserves and riparian areas and increased forest cover, in tandem with an expansion of sugarcane production in the most important producing state, São Paulo.

Yet natural forest in Brazil is being lost, with nearly 37 million acres lost between May 2000 and August 2006, and a total of 150 million acres lost since 1970. Some observers have suggested that the increase in U.S. corn production for biofuel led to reduced soybean output and higher soybean prices, and that these changes led, in turn, to new deforestation in Brazil. However, total deforestation rates in Brazil appear to fall in tandem with rising soybean prices. This co-occurrence illustrates a lack of connection between commodity prices and initial land clearing. This phenomenon has been observed around the globe and suggests an alternate hypothesis: Higher global commodity prices focus production and investment where it can be used most efficiently, in the plentiful previously cleared and underutilized lands around the world. In times of

falling prices and incomes, people return to forest frontiers, with all of their characteristic tribulations, for lack of better options.

Biofuels Done Right

With the right policy framework, cellulosic biofuel crops could offer an alternative that diversifies and boosts rural incomes based on perennials. Such a scenario would create incentives to reduce intentional burning that currently affects millions of acres worldwide each year. Perennial biofuel crops can help stabilize land cover, enhance soil carbon sequestration, provide habitat to support biodiversity, and improve soil and water quality. Furthermore, they can reduce pressure to clear new land via improved incomes and yields. Developing countries have huge opportunities to increase crop yield and thereby grow more food on less land, given that cereal yields in less developed nations are 30% of those in North America. Hence, policies supporting biofuel production may actually help stop the extensive slash-and-burn agricultural cycle that contributes to greenhouse gas emissions, deforestation, land degradation, and a lifestyle that fails to support farmers and their families.

Biofuels alone are not the solution, however. Governments in the United States and elsewhere will have to develop and support a number of programs designed to support sustainable development. The operation and rules of such programs must be transparent, so that everyone can understand them and see that fair play is ensured. Among other attributes, the programs must offer economic incentives for sustainable production, and they must provide for secure land tenure and participatory land-use planning. In this regard, pilot biofuel projects in Africa and Brazil are showing promise in addressing the vexing and difficult challenges of sustainable land use and development. Biofuels also are uniting diverse stakeholders in a global movement to develop sustainability metrics and certification methods applicable to the broader agricultural sector.

Given a priority to protect biodiversity and ecosystem services, it is important to further explore the drivers for the conversion of land at the frontier and to consider the effects, positive and negative, that U.S. biofuel policies could have in these areas. This means it is critical to distinguish between valid concerns calling for caution and alarmist criticisms that attribute complex problems solely to biofuels.

Still, based on the analyses that we and others have done, we believe that biofuels, developed in an economically and environmentally sensible way, can contribute significantly to the nation's—indeed, the world's—energy security while providing a host of benefits for many people in many regions.



Are Biofuels Responsible for Rising Food Prices?

In March 2007, President Bush visited Brazil, which meets much of its need for vehicle fuel with ethanol from sugarcane, and agreed to work with Brazil in developing and promoting biofuels. According to the U.S. State Department, the agreement "reassures small countries in Central America and the Caribbean that they can reduce their dependence on foreign oil." In both Europe and the U.S., governments are rushing to encourage the production and use of biofuels. L. Pelmans, et al., "European Biofuels Strategy," *International Journal of Environmental Studies* (June 2007), attempts to classify nations according to their strategies so that "the formulation of a strategy to support the advancement of biofuels and alternative motor fuels in general should become more manageable." Corporations and investors see huge potential for profit, and many environmentalists see benefits for the environment.

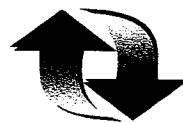
However, there are problems with biofuels, and those problems are getting a great deal of attention. Robin Maynard, "Against the Grain," *The Ecologist* (March 2007), stresses that when food and fuel compete for farmland, food prices will rise, perhaps drastically. The poor will suffer, as will rainforests. Renton Righelato, "Forests or Fuel," *The Ecologist* (March 2007), reminds us that when forests are cleared, they no longer serve as "carbon sinks"; deforestation thus adds to the global warming problem, and it may take a century for the benefit of biofuels to show itself. David Pimentel, "Biofuel Food Disasters and Cellulosic Ethanol Problems," *Bulletin of Science, Technology & Society* (June 2009), says that because using 20 percent of the U.S. corn crop displaces a mere 1 percent of oil consumption, corn ethanol is a disaster, while using crop wastes and other biological materials poses its own problems. Heather Augustyn, "A Burning Issue," *World Watch* (July/August 2007), describes the impact of forest fires to clear land for oil palm plantations in Indonesia. Palm oil holds great promise as a biofuel, but the plantations displace natural ecosystems and destroy habitat for numerous species, as well as for indigenous peoples. Man Kee Lam, et al., "Malaysian Palm Oil: Surviving the Food versus Fuel Dispute for a Sustainable Future," *Renewable & Sustainable Energy Reviews* (August 2009), are more optimistic, saying that with care palm oil may be able to satisfy needs for both edible oils and fuel oils. Gernot Stoeglehner and Michael Narodslawsky, "How Sustainable Are Biofuels? Answers and Further Questions Arising from an Ecological Footprint Perspective," *Bioresource Technology* (August 2009), note that the sustainability of biofuels production depends very much on regional context.

Laura Venderkam, "Biofuels or Bio-Fools?" *American: A Magazine of Ideas* (May/June 2007), describes the huge amounts of money being invested in

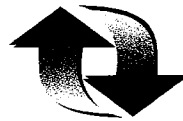
companies planning to bring biofuels to market. A great deal of research is also going on, including efforts to use genetic engineering to produce enzymes that can cheaply and efficiently break cellulose into its component sugars (see Matthew L. Wald, "Is Ethanol for the Long Haul?" *Scientific American*, January 2007, and Michael E. Himmel, et al., "Biomass Recalcitrance: Engineering Plants and Enzymes for Biofuels Production," *Science*, February 9, 2007), make bacteria or yeast that can turn a greater proportion of sugar into alcohol (see Francois Torney, et al., "Genetic Engineering Approaches to Improve Bioethanol Production from Maize," *Current Opinion in Biotechnology*, June 2007), and even bacteria that can convert sugar or cellulose into hydrocarbons that can easily be turned into gasoline or diesel fuel (see Neil Savage, "Building Better Biofuels," *Technology Review*, July/August 2007). If these efforts succeed, the price of biofuels may drop drastically, leading investors to abandon the field. Such a price drop would, of course, benefit the consumer and lead to wider use of biofuels. It would also, say C. Ford Runge and Benjamin Senauer, "How Biofuels Could Starve the Poor," *Foreign Affairs* (May/June 2007) ease the impact on food supply.

Peter Rosset, "Agrofuels, Food Sovereignty, and the Contemporary Food Crisis," *Bulletin of Science, Technology & Society* (June 2009), says that biofuels are not a prime cause of the 2008 food crisis but they are "clearly contraindicated." On the other hand, Jose C. Escobar, et al., "Biofuels: Environment, Technology and Food Security," *Renewable & Sustainable Energy Reviews* (August 2009), considers that increased reliance on biofuels is inevitable due to "the imminent decline of the world's oil production, its high market prices and environmental impacts."

Suzanne Hunt, "Biofuels, Neither Saviour nor Scam: The Case for a Selective Strategy," *World Policy Journal* (Spring 2008), argues that all the concerns are real, but the larger problem is that "our current agricultural, energy, and transport systems are failing." John Ohlrogge, et al., "Driving on Biomass," *Science* (May 22, 2009), point to a potential fix for the failure of the transportation system when they show that converting biomass to biofuels is much less efficient than burning it to produce electricity and using the electricity to power electric cars, which are in fact projected to "gain substantial market share in the coming years."



ISSUE 12



Is It Time to Revive Nuclear Power?

YES: Iain Murray, from "Nuclear Power? Yes, Please," *National Review* (June 16, 2008)

NO: Kristin Shrader-Frechette, from "Five Myths About Nuclear Energy," *America* (June 23–30, 2008)

ISSUE SUMMARY

YES: Iain Murray argues that the world's experience with nuclear power has shown it to be both safe and reliable. Costs can be contained, and if one is concerned about global warming, the case for nuclear power is unassailable.

NO: Professor Kristin Shrader-Frechette argues that nuclear power is one of the most impractical and risky of energy sources. Renewable energy sources such as wind and solar are a sounder choice.

The technology of releasing for human use the energy that holds the atom together did not get off to an auspicious start. Its first significant application was military, and the deaths associated with the Hiroshima and Nagasaki explosions have ever since tainted the technology with negative associations. It did not help that for the ensuing half-century, millions of people grew up under the threat of nuclear Armageddon. But almost from the beginning, nuclear physicists and engineers wanted to put nuclear energy to more peaceful uses, largely in the form of power plants. Touted in the 1950s as an astoundingly cheap source of electricity, nuclear power soon proved to be more expensive than conventional sources, largely because safety concerns caused delays in the approval process and prompted elaborate built-in precautions. Safety measures have worked well when needed—Three Mile Island, often cited as a horrific example of what can go wrong, released very little radioactive material to the environment. The Chernobyl disaster occurred when safety measures were ignored. In both cases, human error was more to blame than the technology itself. The related issue of nuclear waste has also raised fears and proved to add expense to the technology.

It is clear that two factors—fear and expense—impede the wide adoption of nuclear power. If both could somehow be alleviated, it might become possible to gain the benefits of the technology. Among those benefits are that

nuclear power does not burn oil, coal, or any other fuel, does not emit air pollution and thus contribute to smog and haze, does not depend on foreign sources of fuel and thus weaken national independence, and does not emit carbon dioxide. Avoiding the use of fossil fuels is an important benefit; see Robert L. Hirsch, Roger H. Bezdek, and Robert M. Wendling, "Peaking Oil Production: Sooner Rather Than Later?" *Issues in Science and Technology* (Spring 2005). But avoiding carbon dioxide emissions may be more important at a time when society is concerned about global warming, and this is the benefit that prompted James Lovelock, creator of the Gaia Hypothesis and hero to environmentalists everywhere, to say, "If we had nuclear power we wouldn't be in this mess now, and whose fault was it? It was [the anti-nuclear environmentalists]." See his autobiography, *Homage to Gaia: The Life of an Independent Scientist* (Oxford University Press, 2001). Others have also seen this point. The OECD's Nuclear Energy Agency ("Nuclear Power and Climate Change" [Paris, France, 1998] [<http://www.nea.fr/html/ndd/climate/climate.pdf>]) found that a greatly expanded deployment of nuclear power to combat global warming was both technically and economically feasible. Robert C. Morris published *The Environmental Case for Nuclear Power: Economic, Medical, and Political Considerations* (Paragon House) in 2000. "The time seems right to reconsider the future of nuclear power," say James A. Lake, Ralph G. Bennett, and John F. Kotek in "Next-Generation Nuclear Power," *Scientific American* (January 2002). Stewart Brand, long a leading environmentalist, predicts in "Environmental Heresies," *Technology Review* (May 2005), that nuclear power will soon be seen as the "green" energy technology. David Talbot, "Nuclear Powers Up," *Technology Review* (September 2005), notes that "While the waste problem remains unsolved, current trends favor a nuclear renaissance. Energy needs are growing. Conventional energy sources will eventually dry up. The atmosphere is getting dirtier." Peter Schwartz and Spencer Reiss, "Nuclear Now!" *Wired* (February 2005), argue that nuclear power is the one practical answer to global warming and forthcoming shortages of fossil fuels.

In the following selections, Iain Murray of the Competitive Enterprise Institute argues that the world's experience with nuclear power has shown it to be both safe and reliable. Costs can be contained, and if one is concerned about global warming, the case for nuclear power is unassailable. Professor Kristin Shrader-Frechette argues that nuclear power is one of the most impractical and risky of energy sources. Renewable energy sources such as wind and solar are a sounder choice.

YES

Iain Murray

Nuclear Power? Yes, Please

My grandfather was a coal miner. My father was an electrical engineer. Energy appears to be in my blood. In the late 1960s and early 1970s, when I was growing up in the north of England, we seemed to be heading for a new age of energy production. Just to the south of us was a community called Seaton Carew, in the county of Durham. It needed more electricity, and a new coal-fired power station was proposed. The people objected, and a emeritus professor of energy conversion at the nearby University of Newcastle-upon-Tyne puts it, they said, "Why can't we have one of those new, clean nuclear power stations?" My neighbors got their wish. In 1969, work began on the Hartlepool Nuclear Plant. Since 1983, it has provided 3 percent of the United Kingdom's energy.

Next year, decommissioning work will begin on the plant. The local people are opposed to a replacement nuclear facility. What happened? The answer is strangely universal. Around the Western world, environmentalists did what they do best: They exploited fear and massaged science to make nuclear power morally unacceptable, impeding progress and innovation. Yet today they find their case weakened—perhaps fatally—by another concern born from another campaign of fear: global warming. The hysteria environmentalists have built up around carbon emissions may lead to a new dawn for nuclear power. Given that, the case for new nuclear is almost unassailable.

Throughout the late 1960s and early 1970s, there was considerable technical discussion about the safety of nuclear power throughout the world, and local court cases against new construction had been common. The Calvert Cliffs Coordinating Committee, for example, delayed the building of a reactor in Maryland after a court victory over the Atomic Energy Commission in 1971. Construction on subsequent projects slowed as a result. Mass popular opposition to the "new, clean nuclear power stations" worldwide, however, seems to have begun in Germany. Shortly after work started in Hartlepool, a new plant was proposed for the tiny southwest German village of Wyhl. Opposition grew and, by the time work began in 1975, a mass movement was ready. Thirty thousand protesters gathered, seized control of the site, and occupied it. The plant was never built.

The German protesters did not rest on their laurels after this victory. In 1977, 20,000 people protested the use of salt mines at Gorleben for nuclear-waste storage. Growing bolder, they turned to open violence. At Brokdorf in

1981, 100,000 demonstrators surrounded the site of a proposed nuclear plant, confronting 10,000 police. According to the *New York Times* report, "groups of hundreds of demonstrators armed with gasoline bombs, sticks, stones and high-powered slingshots" attacked the police, injuring 21 of them.

It was about this time that I noticed a cultural invasion of England by Germany. Dozens of students at my high school started sporting large yellow buttons depicting a smiley-faced sun surrounded by the German words "ATOMKRAFT? NEIN DANKE!" ("Nuclear power? No thanks!") In 1979, the movement had reached such levels of power that it was able to establish its own sustainable political party. Die Grünen (the Greens) had among their early leaders a roll call of radical leftists. Among them was the tiny and articulate Petra Kelly, a former European Commission bureaucrat who had been educated in the United States and had worked on the Robert F. Kennedy and Hubert Humphrey campaigns in 1968. Others included former student radical Rudi Dutschke, who followed Gramsci in advocating a "long march through the institutions," the novelist Heinrich Böll, and the artist Joseph Beuys. Anti-nuclear activism was the core of their appeal and remains a central plank today. They have indeed marched through the institutions, even claiming the foreign ministry from 1998 to 2005 and entering into a state-level coalition with Germany's nominal conservatives, the Christian Democrats. The Green virus spread dramatically out from Germany, infecting the politics of most developed nations.

I have spent a little time outlining this early history because it is important to recognize that the anti-nuclear movement was already ascendant before the Three Mile Island incident in 1979. On May 2, 1977, no doubt inspired by the German protesters, 1,414 people were arrested protesting a nuclear plant in Seabrook, N.H. Three Mile Island merely galvanized an already-active movement. Nuclear-plant orders had in fact peaked in 1973, and fell off sharply after 1974 as energy-conservation concerns reigned supreme in the wake of the Arab oil embargo. . . . The anti-nuclear movement's achievement was not to stop nuclear power, but to take it off the table as an option after 1979.

Fear and Loathing

How did they succeed? By creating a global zeitgeist—an appropriately German word—holding as an article of faith that nuclear power is a severe danger in all sorts of ways. Their arguments revolved around three main propositions: that nuclear plants are dangerous because they can blow up or melt down; that nuclear waste is extremely and persistently dangerous; and that nuclear power and nuclear weapons are intrinsically linked. All these arguments are overstated.

As to the safety of nuclear power stations, there is now a significant history to demonstrate that these concerns are no longer justified, even if they may have had some precautionary legitimacy in the 1970s. It has long been recognized that the Chernobyl accident was caused by features unique to the Soviet-style RBMK (*reaktor bolsшой moshchnosti kanalniy*—high-power channel reactor). When reactors of that sort get too hot, the rate of the nuclear

From *The National Review*, June 16, 2008, pp. 32, 34–36. Copyright © 2008 by National Review, Inc., 215 Lexington Avenue, New York, NY 10016. Reprinted by permission.

reaction increases—the reverse of what happens in most Western reactors. Moreover, RBMK reactors do not have containment shells that prevent radioactive material from getting out. The worst incident in the history of nuclear power, Chernobyl killed just 56 people and made 20 square miles of land uninhabitable. (The exclusion zone has now become a haven for wildlife, which is thriving.) There are suggestions that hundreds or thousands more may die because of long-term effects, but these estimates are based on the controversial Linear Non-Threshold (LNT) theory about the effects of radiation.

Official EPA doctrine, based on the LNT theory, holds that no level of radiation is safe, and that the maximum allowable exposure to radiation is an extremely stringent 15 millirems (mrem) per year. After Hiroshima and Nagasaki, researchers discovered that 600,000 mrem was a sufficient dose of radiation to kill anyone exposed to it, and 400,000 mrem killed half the people exposed. Symptoms of radiation sickness develop at 75,000–100,000 mrem. By extrapolating linearly, the model holds that there is no level of radiation at which someone is not adversely affected (hence “nonthreshold”). Therefore, if a million people are exposed to a very low dose of radiation—say 500 mrem—then 6,250 of them will die of cancer brought on by the exposure. At least according to the theory.

But this is mere assumption, with no epidemiological evidence to back it up. As Prof. Donald W. Miller Jr. of the University of Washington School of Medicine wrote in 2004, “Known and documented health-damaging effects of radiation—radiation sickness, leukemia, and death—are only seen with doses greater than 100 rem [which is to say, 100,000 mrem]. The risk of doses less than 100 rem is a black box into which regulators extend ‘extrapolated data.’ There are no valid epidemiologic or experimental data to support linearly extrapolated predictions of cancer resulting from low doses of radiation.”

In fact, Americans are naturally exposed to around 200 mrem a year of background radiation. In some places around the world that background level is much higher. In Ramsar, Iran, thanks to the presence of natural radium in the vicinity, residents get 26,000 mrem a year, but there is no increased incidence of cancer or shortened lifespan. This is a real problem for the LNT theory. The predicted deaths and cancer cases haven’t materialized.

In Britain, much hay was made by Greenpeace and other organizations of the emergence of greater incidences of leukemia in children living near the nuclear-reprocessing plant at Sellafield in the early 1990s. But such “cancer clusters” appear all over the place, and are just as likely to appear next to an organic farm—to borrow the formulation of British environment writer Rob Johnston—as next to a nuclear facility. There does not appear to be any greater incidence of leukemia in the children of those who work in the nuclear industry. In fact, there is so little evidence of significant safety risks related to nuclear power that the British government “continues to believe that new nuclear power stations would pose very small risks to safety, security, health and proliferation,” according to a recent analysis it undertook. It also believes that “these risks are minimized and sensibly managed by industry.”

Nuclear waste is a stickier problem, but one that can be safely managed. In most American reactors, fuel rods need to be replaced every 18 months or so. When they are taken out, they contain large amounts of radioactive fission products and produce enough heat that they need to be cooled in water. Radioactivity declines as the isotopes decay and the rods produce less heat. It is the very nature of radioactivity that, as materials decay, they become less dangerous and easier to handle. The question is what to do with the waste when space runs out.

In most of the rest of the world, fuel reprocessing extracts usable uranium and plutonium. The highly radioactive waste that remains is not a large amount. By 2040, Britain will have just 70,000 cubic feet of such waste. This volume could be contained in a cube measuring 42 feet on each side. Moreover, most of Britain’s waste is left over from its nuclear-weapons program. The British government has determined that “geological disposal”—burial deep underground—provides the best available approach to dealing with existing and also with new nuclear waste, arguing that “the balance of ethical considerations does not rule out the option of new nuclear power.”

In the United States, unfortunately, reprocessing was stopped during the Carter administration, in the naïve belief that other countries would follow suit and thereby reduce the amount of plutonium available for weapons proliferation. For that reason, the United States has rather more nuclear waste than any other nation, about 144 million pounds of it. Since 1987, the United States has focused its own efforts at geological disposal at a remote Nevada site called Yucca Mountain, located within a former nuclear-test facility.

The story of Yucca Mountain is well-known—it has become a political football as pro- and anti-nuclear forces try to accelerate or delay (or even stop) the facility’s commissioning. Legal challenges have focused on the question of how much radiation will escape to the public from the facility—over a timeline of a million years. The Department of Energy has calculated that exposure will be no more than 0.98 mrem per year, up to a million years into the future. Even those who hold to the stringent LNT view of radiation should be satisfied.

With that settled, the Department of Energy announced in 2006 that Yucca Mountain would open for business in 2017. But later that year, when Harry Reid was chosen as Senate majority leader, he announced, “Yucca Mountain is dead. It’ll never happen.” The project’s budget has been slashed. As a result, the question of storing America’s nuclear waste remains open, even as more and more of that waste piles up around the country.

On the issue of persistence, bear in mind that reprocessing the fuel means that, after ten years, the fission products are only one-thousandth as radioactive as they were initially. After 500 years, they will be less radioactive than the uranium ore they originally came from. The waste question is therefore simply one of storage. It is a political, not a scientific, dispute.

As for the problem of nuclear proliferation, the unpleasant fact is that every country that has been willing to invest the time and effort required to make a nuclear weapon has succeeded. The existence of nuclear power plants in Western countries has nothing to do with this. In fact, in order to keep plants economical, fuel rods are kept in the reactor long enough that

the weapons-grade plutonium, Pu-239, absorbs another neutron and becomes the much less dangerous Pu-240. To be effective in a weapon, a given volume of plutonium must contain no more than 7 percent Pu-240. Spent fuel from civilian nuclear plants is typically composed of about 26 percent Pu-240. This makes it extremely difficult even for experts to use in the manufacture of nuclear weapons—and well nigh impossible for amateurs.

There is some concern that nuclear power plants present an attractive target for terrorists. After the attacks of Osama bin Laden's impromptu air force in 2001, the Department of Energy commissioned a study into the effects of a fully fueled jetliner's hitting a reactor containment vessel at maximum speed. In none of the simulations was containment breached. Given the massive investment that would be needed to compromise a nuclear power station, it is highly unlikely that terrorists would seek to attack such a hard target—especially when their revealed preference has been for soft targets offering the maximum possible loss of civilian life.

The world's experience with nuclear power, therefore, has confounded the arguments of the environmentalists. It has proven safe and reliable—and if you still need convincing of this, remember that the second-worst nuclear incident, Three Mile Island, saw a destroyed reactor confined with no casualties.

Environmental Economics

With safety concerns off the table, the real question remaining as to whether we should move forward with nuclear power is one of economics. Up until now, the high costs of construction and decommissioning have made nuclear more expensive than coal and natural gas. That, however, is likely to change, and it is the environmentalists who will have brought about the change.

The Congressional Budget Office recently released a report finding that nuclear power costs around \$72 per megawatt-hour of energy, compared with \$55 for coal and \$57 for natural gas. But those estimates reflect very high construction costs. When it comes to operating costs, nuclear power is much less expensive. Therefore, the economics of nuclear power depend to a large extent on reducing those construction costs—both the direct costs of building (which is highly dependent on construction time) and the costs of regulation. It should be feasible to reduce significantly the costs of regulation by various means. Under its Nuclear Power 2010 program, for example, the U.S. Department of Energy has offered interested parties the opportunity to operate under a surprisingly non-bureaucratic model for licensing based on the French system. (Less responsibly, for the first six plants, the program also offers to subsidize 25 percent to 50 percent of any construction-cost overruns due to delays.) Nuclear plants have never been built anywhere in an environment of low regulatory costs, so it is hard to estimate to what degree deregulation could reduce expenses without jeopardizing safety.

Those high construction costs have led many to argue that nuclear power is intrinsically uneconomic without subsidy. This is contradicted by the British government's recent analysis, which found that nuclear power is viable without subsidies. The British government received confirmation from potential nuclear

operators that subsidy was neither needed nor desired. In the United States, there have been 30 announcements of plans for new nuclear plants, totaling 40,000 megawatts of capacity, which would power 32 million households.

In all the hysteria about global warming, environmentalists have, for the most part, agreed on one thing above all—that the use of fossil fuels must be made more expensive. Every proposal currently under consideration for the reduction of greenhouse-gas emissions seeks to raise prices as a brake on emissions, through either a cap-and-trade system or a carbon tax. Once this expense is included in the calculations, nuclear power becomes extremely competitive, and remains considerably cheaper than wind power. The Congressional Budget Office found that nuclear power is the most attractive source of electricity once the price of carbon emissions reaches \$45 a ton. If natural-gas prices increase as rapidly as they have done recently, then that figure will come down even further. The British-government review found that nuclear provides "economic benefit regardless of the carbon price." Moreover, it provides carbon reductions much more cheaply than wind power does. Using nuclear power, it costs 60 cents to eliminate a ton of CO₂ emissions, as opposed to a staggering \$100 per ton for onshore wind power. It is true that a carbon tax amounts to a subsidy for nuclear power. But if carbon emissions are to be taxed, then that is the only subsidy that nuclear power will ever need.

Keep in mind that many of the current arguments used against nuclear power by environmentalists are economic in tone—that uranium is running out (not true even in the medium term); that decommissioning is expensive and/or will be a burden on the taxpayer (it is expensive, but the cost could be met by requiring the operator to pay into a fund during the reactor's life); or that building reactors takes too long (true, but most of that is the fault of red tape). The Canadian company ACEL has managed to shorten the time for building a reactor—from groundbreaking to coming online—to four years. Such a schedule should significantly reduce construction costs which, as we have seen, are the main impediment to nuclear cost-effectiveness.

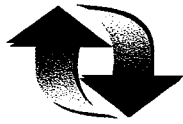
Nuclear Is Greener

Beyond economics, if you take seriously the issue of greenhouse gases—whether as a climate alarmist or as someone with an open mind who believes in a degree of prudence—then the case for nuclear power is unassailable. James Lovelock, famous as the father of the "Gaia Hypothesis," has said nuclear power represents humanity's only hope to escape runaway global warming. Yet most environmental groups refuse to recognize the impracticality of opposing both greenhouse-gas emissions and our most effective way of reducing them. For those groups, the problem isn't "dirty" energy, but energy itself. They presumably agree with one of their sages, Amory Lovins, who told *Playboy* in 1977, "It'd be a little short of disastrous for us to discover a source of clean, cheap, abundant energy because of what we might do with it."

For the rest of us, what we might do with it is the whole point—we might increase human prosperity and welfare. If we're determined to price coal out of the energy market, then nuclear is it. If we're determined to cure our

"addition to oil," then we will need nuclear facilities to power our plug-in hybrid electric cars or to make the hydrogen for our fuel cells. This is not a green pipe dream. In fact, given the way automotive technology is developing, it is plausible that a majority of vehicles sold in the U.S. by 2020 will use electric power trains, increasing our need for electricity. We might not even need to close our coal mines, since we can get more energy from the uranium found in coal than from burning the coal itself.

Those denizens of Seaton Carew had it right. Nuclear power is clean. In a sense it is still new. Thirty years after their radical predecessors took nuclear energy away from the people of the world, environmentalists might have inadvertently given it back. *Atomkraft? Ja, bitte!*



Kristin Shrader-Frechette



NO

Five Myths About Nuclear Energy

Atomic energy is among the most impractical and risky of available fuel sources. Private financiers are reluctant to invest in it, and both experts and the public have questions about the likelihood of safely storing lethal radioactive wastes for the required million years. Reactors also provide irresistible targets for terrorists seeking to inflict deep and lasting damage on the United States. The government's own data show that U.S. nuclear reactors have more than a one-in-five lifetime probability of core melt, and a nuclear accident could kill 140,000 people, contaminate an area the size of Pennsylvania, and destroy our homes and health.

In addition to being risky, nuclear power is unable to meet our current or future energy needs. Because of safety requirements and the length of time it takes to construct a nuclear-power facility, the government says that by the year 2050 atomic energy could supply, at best, 20 percent of U.S. electricity needs; yet by 2020, wind and solar panels could supply at least 32 percent of U.S. electricity, at about half the cost of nuclear power. Nevertheless, in the last two years, the current U.S. administration has given the bulk of taxpayer energy subsidies—a total of \$20 billion—to atomic power. Why? Some officials say nuclear energy is clean, inexpensive, needed to address global climate change, unlikely to increase the risk of nuclear proliferation and safe.

On all five counts they are wrong. Renewable energy sources are cleaner, cheaper, better able to address climate change and proliferation risks, and safer. The government's own data show that wind energy now costs less than half of nuclear power; that wind can supply far more energy, more quickly, than nuclear power; and that by 2015, solar panels will be economically competitive with all other conventional energy technologies. The administration's case for nuclear power rests on at least five myths. Debunking these myths is necessary if the United States is to abandon its current dangerous energy course.

Myth 1. Nuclear Energy Is Clean

The myth of clean atomic power arises partly because some sources, like a pro-nuclear energy analysis published in 2003 by several professors at the Massachusetts Institute of Technology, call atomic power a "carbon-free source" of energy. On its Web site, the U.S. Department of Energy, which is

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also a proponent of nuclear energy, calls atomic power "emissions free." At best, these claims are half-truths because they "trim the data" on emissions.

While nuclear reactors themselves do not release greenhouse gases, reactors are only part of the nine-stage nuclear fuel cycle. This cycle includes mining uranium ore, milling it to extract uranium, converting the uranium to gas, enriching it, fabricating fuel pellets, generating power, reprocessing spent fuel, storing spent fuel at the reactor and transporting the waste to a permanent storage facility. Because most of these nine stages are heavily dependent on fossil fuels, nuclear power thus generates at least 33 grams of carbon-equivalent emissions for each kilowatt-hour of electricity that is produced. (To provide uniform calculations of greenhouse emissions, the various effects of the different greenhouse gases typically are converted to carbon-equivalent emissions.) Per kilowatt-hour, atomic energy produces only one-seventh the greenhouse emissions of coal, but twice as much as wind and slightly more than solar panels.

Nuclear power is even less clean when compared with energy-efficiency measures, such as using compact-fluorescent bulbs and increasing home insulation. Whether in medicine or energy policy, preventing a problem is usually cheaper than curing or solving it, and energy efficiency is the most cost-effective way to solve the problem of reducing greenhouse gases. Department of Energy data show that one dollar invested in energy-efficiency programs displaces about six times more carbon emissions than the same amount invested in nuclear power. Government figures also show that energy-efficiency programs save \$40 for every dollar invested in them. This is why the government says it could immediately and cost-effectively cut U.S. electricity consumption by 20 percent to 45 percent, using only existing strategies, like time-of-use electricity pricing. (Higher prices for electricity used during daily peak-consumption times—roughly between 8 a.m. and 8 p.m.—encourage consumers to shift their time of energy use. New power plants are typically needed to handle only peak electricity demand.)

Myth 2. Nuclear Energy Is Inexpensive

Achieving greater energy efficiency, however, also requires ending the lopsided system of taxpayer nuclear subsidies that encourage the myth of inexpensive electricity from atomic power. Since 1949, the U.S. government has provided about \$165 billion in subsidies to nuclear energy, about \$5 billion to solar and wind together, and even less to energy-efficiency programs. All government efficiency programs—to encourage use of fuel-efficient cars, for example, or to provide financial assistance so that low-income citizens can insulate their homes—currently receive only a small percentage of federal energy monies.

After energy-efficiency programs, wind is the most cost-effective way both to generate electricity and to reduce greenhouse emissions. It costs about half as much as atomic power. The only nearly finished nuclear plant in the West, now being built in Finland by the French company Areva, will generate electricity costing 11 cents per kilowatt-hour. Yet the U.S. government's Lawrence Berkeley National Laboratory calculated actual costs of new wind

WHAT DOES THE CHURCH SAY?

Though neither the Vatican nor the U.S. bishops have made a statement on nuclear power, the church has outlined the ethical case for renewable energy. In *Centesimus Annus* Pope John Paul II wrote that just as Pope Leo XIII in 1891 had to confront "primitive capitalism" in order to defend workers' rights, he himself had to confront the "new capitalism" in order to defend collective goods like the environment. Pope Benedict XVI warned that pollutants "make the lives of the poor especially unbearable." In their 2001 statement *Global Climate Change*, the U.S. Catholic bishops repeated his point: climate change will "disproportionately affect the poor, the vulnerable, and generations yet unborn."

The bishops also warn that "misguided responses to climate change will likely place even greater burdens on already desperately poor peoples." Instead they urge "energy conservation and the development of alternate renewable and clean-energy resources." They argue that renewable energy promotes care for creation and the common good, lessens pollution that disproportionately harms the poor and vulnerable, avoids threats to future generations and reduces nuclear-proliferation risks.

plants, over the last seven years, at 3.4 cents per kilowatt-hour. Although some groups say nuclear energy is inexpensive, their misleading claims rely on trimming the data on cost. The 2003 M.I.T. study, for instance, included neither the costs of reprocessing nuclear material, nor the full interest costs on nuclear-facility construction capital, nor the total costs of waste storage. Once these omissions—from the entire nine-stage nuclear fuel cycle—are included, nuclear costs are about 11 cents per kilowatt-hour.

The cost-effectiveness of wind power explains why in 2006 utility companies worldwide added 10 times more wind-generated, than nuclear, electricity capacity. It also explains why small-scale sources of renewable energy, like wind and solar, received \$56 billion in global private investments in 2006, while nuclear energy received nothing. It explains why wind supplies 20 percent of Denmark's electricity. It explains why, each year for the last several years, Germany, Spain and India have each, alone, added more wind capacity than all countries in the world, taken together, have added in nuclear capacity.

In the United States, wind supplies up to 8 percent of electricity in some Midwestern states. The case of Louis Brooks is instructive. Utilities pay him \$500 a month for allowing 78 wind turbines on his Texas ranch, and he can still use virtually all the land for farming and grazing. Wind's cost-effectiveness also explains why in 2007 wind received \$9 billion in U.S. private investments, while nuclear energy received zero. U.S. wind energy has been growing by nearly 3,000 megawatts each year, annually producing new electricity

equivalent to what three new nuclear reactors could generate. Meanwhile, no new U.S. atomic-power reactors have been ordered since 1974.

Should the United States continue to heavily subsidize nuclear technology? Or, as the distinguished physicist Amory Lovins put it, is the nuclear industry dying of an "incurable attack of market forces"? Standard and Poor's, the credit- and investment-rating company, downgrades the rating of any utility that wants a nuclear plant. It claims that even subsidies are unlikely to make nuclear investment wise. *Forbes* magazine recently called nuclear investment "the largest managerial disaster in business history," something pursued only by the "blind" or the "biased."

Myth 3. Nuclear Energy Is Necessary to Address Climate Change

Government, industry and university studies, like those recently from Princeton, agree that wind turbines and solar panels already exist at an industrial scale and could supply one-third of U.S. electricity needs by 2020, and the vast majority of U.S. electricity by 2050—not just the 20 percent of electricity possible from nuclear energy by 2050. The D.O.E. says wind from only three states (Kansas, North Dakota and Texas) could supply all U.S. electricity needs, and 20 states could supply nearly triple those needs. By 2015, according to the D.O.E., solar panels will be competitive with all conventional energy technologies and will cost 5 to 10 cents per kilowatt hour. Shell Oil and other fossil-fuel companies agree. They are investing heavily in wind and solar.

From an economic perspective, atomic power is inefficient at addressing climate change because dollars used for more expensive, higher-emissions nuclear energy cannot be used for cheaper, lower-emissions renewable energy. Atomic power is also not sustainable. Because of dwindling uranium supplies, by the year 2050 reactors would be forced to use low-grade uranium ore whose greenhouse emissions would roughly equal those of natural gas. Besides, because the United States imports nearly all its uranium, pursuing nuclear power continues the dangerous pattern of dependency on foreign sources to meet domestic energy needs.

Myth 4. Nuclear Energy Will Not Increase Weapons Proliferation

Pursuing nuclear power also perpetuates the myth that increasing atomic energy, and thus increasing uranium enrichment and spent-fuel reprocessing, will increase neither terrorism nor proliferation of nuclear weapons. This myth has been rejected by both the International Atomic Energy Agency and the U.S. Office of Technology Assessment. More nuclear plants means more weapons materials, which means more targets, which means a higher risk of terrorism and proliferation. The government admits that Al Qaeda already has targeted U.S. reactors, none of which can withstand attack by a large airplane. Such an attack, warns the U.S. National Academy of Sciences, could cause fatalities as

far away as 500 miles and destruction 10 times worse than that caused by the nuclear accident at Chernobyl in 1986.

Nuclear energy actually increases the risks of weapons proliferation because the same technology used for civilian atomic power can be used for weapons, as the cases of India, Iran, Iraq, North Korea and Pakistan illustrate. As the Swedish Nobel Prize winner Hannes Alven put it, "The military atom and the civilian atom are Siamese twins." Yet if the world stopped building nuclear-power plants, bomb ingredients would be harder to acquire, more conspicuous and more costly politically, if nations were caught trying to obtain them. Their motives for seeking nuclear materials would be unmasked as military, not civilian.

Myth 5. Nuclear Energy Is Safe

Proponents of nuclear energy, like Patrick Moore, cofounder of Greenpeace, and the former Argonne National Laboratory adviser Steve Berry, say that new reactors will be safer than current ones—"melt-down proof." Such safety claims also are myths. Even the 2003 M.I.T. energy study predicted that tripling civilian nuclear reactors would lead to about four core-melt accidents. The government's Sandia National Laboratory calculates that a nuclear accident could cause casualties similar to those at Hiroshima or Nagasaki: 140,000 deaths. If nuclear plants are as safe as their proponents claim, why do utilities need the U.S. Price-Anderson Act, which guarantees utilities protection against 98 percent of nuclear-accident liability and transfers these risks to the public? All U.S. utilities refused to generate atomic power until the government established this liability limit. Why do utilities, but not taxpayers, need this nuclear-liability protection?

Another problem is that high-level radioactive waste must be secured "in perpetuity," as the U.S. National Academy of Sciences puts it. Yet the D.O.E. has already admitted that if nuclear waste is stored at Nevada's Yucca Mountain, as has been proposed, future generations could not meet existing radiation standards. As a result, the current U.S. administration's proposal is to allow future releases of radioactive wastes, stored at Yucca Mountain, provided they annually cause no more than one person—out of every 70 persons exposed to them—to contract fatal cancer. These cancer risks are high partly because Yucca Mountain is so geologically unstable. Nuclear waste facilities could be breached by volcanic or seismic activity. Within 50 miles of Yucca Mountain, more than 600 seismic events, of magnitude greater than two on the Richter scale, have occurred since 1976. In 1992, only 12 miles from the site, an earthquake (5.6 on the Richter scale) damaged D.O.E. buildings. Within 31 miles of the site, eight volcanic eruptions have occurred in the last million years. These facts suggest that Alvin Weinberg was right. Four decades ago, the then-director of the government's Oak Ridge National Laboratory warned that nuclear waste required society to make a Faustian bargain with the devil. In exchange for current military and energy benefits from atomic power, this generation must sell the safety of future generations.

Yet the D.O.E. predicts harm even in this generation. The department says that if 70,000 tons of the existing U.S. waste were shipped to Yucca Mountain,

the transfer would require 24 years of dozens of daily rail or truck shipments. Assuming low accident rates and discounting the possibility of terrorist attacks on these lethal shipments, the D.O.E. says this radioactive-waste transport likely would lead to 50 to 310 shipment accidents. According to the D.O.E., each of these accidents could contaminate 42 square miles, and each could require a 462-day cleanup that would cost \$620 million, not counting medical expenses. Can hundreds of thousands of mostly unguarded shipments of lethal materials be kept safe? The states do not think so, and they have banned Yucca Mountain transport within their borders. A better alternative is onsite storage at reactors, where the material can be secured from terrorist attack in "hardened" bunkers.

Where Do We Go From Here?

If atomic energy is really so risky and expensive, why did the United States begin it and heavily subsidize it? As U.S. Atomic Energy Agency documents reveal, the United States began to develop nuclear power for the same reason many other nations have done so. It wanted weapons-grade nuclear materials for its military program. But the United States now has more than enough weapons materials. What explains the continuing subsidies? Certainly not the market. *The Economist* (7/7/05) recently noted that for decades, bankers in New York and London have refused loans to nuclear industries. Warning that nuclear costs, dangers and waste storage make atomic power "extremely risky," *The Economist* claimed that the industry is now asking taxpayers to do what the market will not do: invest in nuclear energy. How did *The Economist* explain the uneconomical \$20 billion U.S. nuclear subsidies for 2005-7? It pointed to campaign contributions from the nuclear industry.

Despite the problems with atomic power, society needs around-the-clock electricity. Can we rely on intermittent wind until solar power is cost-effective in 2015? Even the Department of Energy says yes. Wind now can supply up to 20 percent of electricity, using the current electricity grid as backup, just as nuclear plants do when they are shut down for refueling, maintenance and leaks. Wind can supply up to 100 percent of electricity needs by using "distributed" turbines spread over a wide geographic region—because the wind always blows somewhere, especially offshore.

Many renewable energy sources are safe and inexpensive, and they inflict almost no damage on people or the environment. Why is the current U.S. administration instead giving virtually all of its support to a riskier, more costly nuclear alternative?

POSTSCRIPT



Is It Time to Revive Nuclear Power?

Robert Evans, "Nuclear Power: Back in the Game," *Power Engineering* (October 2005), reports that a number of power companies are considering new nuclear power plants. See also Eliot Marshall, "Is the Friendly Atom Poised for a Comeback?" and Daniel Clery, "Nuclear Industry Dares to Dream of a New Dawn," *Science* (August 19, 2005). Nuclear momentum is growing, says Charles Petit, "Nuclear Power: Risking a Comeback," *National Geographic* (April 2006), thanks in part to new technologies. One motive is stability of energy supply; see "Why Go Nuclear? Perspectives from the United Arab Emirates, Jordan, Egypt, & Thailand," *Bulletin of the Atomic Scientists* (September/October 2008). Diane Farsetta, "The Campaign to Sell Nuclear," *Bulletin of the Atomic Scientists* (September/October 2008), calls the current effort to revive nuclear power just the latest of the industry's public relations campaigns. Karen Charman, "Brave Nuclear World?" (Part I) *World Watch* (May/June 2006), objects that producing nuclear fuel uses huge amounts of electricity derived from fossil fuels, so going nuclear can hardly prevent all releases of carbon dioxide (although using electricity derived from nuclear power would reduce the problem). She also notes that "Although no comprehensive and integrated study comparing the collateral and external costs of energy sources globally has been done, all currently available energy sources have them. . . . Burning coal—the single largest source of air pollution in the U.S.—causes global warming, acid rain, soot, smog, and other toxic air emissions and generates waste ash, sludge, and toxic chemicals. Landscapes and ecosystems are completely destroyed by mountaintop removal mining, while underground mining imposes high fatality, injury, and sickness rates. Even wind energy kills birds, can be noisy, and, some people complain, blights landscapes."

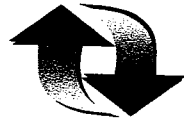
Michael J. Wallace tells us that there are 103 nuclear reactors operating in the United States today. Stephen Ansolabehere, et al., "The Future of Nuclear Power," *An Interdisciplinary MIT Study* (MIT, 2003), note that in 2000 there were 352 in the developed world as a whole, and a mere 15 in developing nations. Even a very large increase in the number of nuclear power plants—to 1,000 to 1,500—will not stop all releases of carbon dioxide. In fact, if carbon emissions double by 2050 as expected, from 6,500 to 13,000 million metric tons per year, the 1,800 million metric tons not emitted because of nuclear power will seem relatively insignificant. Nevertheless, say John M. Deutch and Ernest J. Moniz, "The Nuclear Option," *Scientific American* (September 2006), such a cut in carbon emissions would be "significant." Christine Laurent, in "Beating Global Warming with Nuclear Power?" *UNESCO Courier* (February 2001), notes, "For several years, the nuclear energy industry has attempted to cloak itself in different ecological robes. Its credo: nuclear energy is a formidable

asset in battle against global warming because it emits very small amounts of greenhouse gases. This stance, first presented in the late 1980s when the extent of the phenomenon was still the subject of controversy, is now at the heart of policy debates over how to avoid droughts, downpours and floods." Laurent adds that it makes more sense to focus on reducing carbon emissions by reducing energy consumption.

The debate over the future of nuclear power is likely to remain vigorous for some time to come. But as Richard A. Meserve says in a *Science* editorial ("Global Warming and Nuclear Power," *Science* [January 23, 2004]), "For those who are serious about confronting global warming, nuclear power should be seen as part of the solution. Although it is unlikely that many environmental groups will become enthusiastic proponents of nuclear power, the harsh reality is that any serious program to address global warming cannot afford to jettison any technology prematurely. . . . The stakes are large, and the scientific and educational community should seek to ensure that the public understands the critical link between nuclear power and climate change." Paul Lorenzini, "A Second Look at Nuclear Power," *Issues in Science and Technology* (Spring 2005), argues that the goal must be energy "sufficiency for the foreseeable future with minimal environmental impact." Nuclear power can be part of the answer, but making it happen requires that we shed ideological biases. "It means ceasing to deceive ourselves about what might be possible."

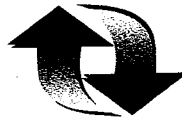
Alvin M. Weinberg, former director of the Oak Ridge National Laboratory, notes in "New Life for Nuclear Power," *Issues in Science and Technology* (Summer 2003), that to make a serious dent in carbon emissions would require perhaps four times as many reactors as suggested in the MIT study. The accompanying safety and security problems would be challenging. If the challenges can be met, says John J. Taylor, retired vice president for nuclear power at the Electric Power Research Institute, in "The Nuclear Power Bargain," *Issues in Science and Technology* (Spring 2004), there are a great many potential benefits. Are new reactor technologies needed? Richard K. Lester, "New Nukes," *Issues in Science and Technology* (Summer 2006), says that better centralized waste storage is what is needed, at least in the short term. See also Elizabeth Svoboda, "Back to the Atom," *Discover* (June 2009).

Environmental groups such as Friends of the Earth are adamantly opposed, but there are signs that some environmentalists do not agree; see William M. Welch, "Some Rethinking Nuke Opposition," *USA Today* (March 23, 2007). Judith Lewis, "The Nuclear Option," *Mother Jones* (May/June 2008), concludes that "[w]hen rising seas flood our coasts, the idea of producing electricity from the most terrifying force ever harnessed may not seem so frightening—or expensive—at all." However, notes Mariah Blake, "Bad Reactors," *Washington Monthly* (January/February 2009), building large numbers of reactors will be expensive and may take much longer than proponents say; expanded nuclear power just may not become available soon enough to do much good. The cost issue is also stressed by Aaron M. Cohen, "Cost May Threaten Nuclear Power's Future," *The Futurist* (May/June 2009).



contamination. An updated version of this report, *Poison PCs and Toxic TVs: E-Waste Tsunami to Roll Across the US: Are We Prepared?*, was released in February 2004. In August 2005, Greenpeace released K. Brigden, et al., *Recycling of Electronic Wastes in China and India: Workplace and Environmental Contamination* (http://www.e-takeback.org/press_open/greenpeace.pdf). Currently the problem of electronic waste continues to grow; see Elisabeth Jeffries, "E-Wasted," *World Watch* (July/August 2006).

Among the solutions that have been urged to address the hazardous waste problem are "take-back" and "remanufacturing" practices. Gary A. Davis and Catherine A. Wilt, in "Extended Product Responsibility," *Environment* (September 1997), urge such solutions as crucial to the minimization of waste and describe how they are becoming more common in Europe. Brad Stone, "Tech Trash, E-Waste: By Any Name, It's an Issue," *Newsweek* (December 12, 2005), describes their appearance in the United States, where some states are making take-back programs mandatory for computers, televisions, and other electronic devices. After *Exporting Harm* was published and drew considerable attention from the press, some industry representatives hastened to emphasize such practices as Hewlett Packard's recycling of printer ink cartridges. See Doug Bartholomew's "Beyond the Grave," *Industry Week* (March 1, 2002), which also stressed the need to minimize waste by intelligent design. The Institute of Industrial Engineers published in its journal *IIE Solutions* Brian K. Thorn's and Philip Rogerson's "Take It Back" (April 2002), which stressed the importance of designing for reuse or remanufacturing. Anthony Brabazon and Samuel Idowu, in "Costing the Earth" *Financial Management (CIMA)* (May 2001), note that "take-back schemes may [both] provide opportunities to build goodwill and [help] companies to use resources more efficiently."



ISSUE 19

Should the United States Reprocess Spent Nuclear Fuel?

YES: Phillip J. Finck, from Statement before the House Committee on Science, Energy Subcommittee, Hearing on Nuclear Fuel Reprocessing (June 16, 2005)

NO: Charles D. Ferguson, "An Assessment of the Proliferation Risks of Spent Fuel Reprocessing and Alternative Nuclear Waste Management Strategies," from Testimony before the U.S. House of Representatives Committee on Science and Technology Hearing on Advancing Technology for Nuclear Fuel Recycling: What Should Our Research, Development and Demonstration Strategy Be? (June 17, 2009).

ISSUE SUMMARY

YES: Phillip J. Finck argues that by reprocessing spent nuclear fuel, the United States can enable nuclear power to expand its contribution to the nation's energy needs while reducing carbon emissions, nuclear waste, and the need for waste repositories such as Yucca Mountain.

NO: Charles D. Ferguson, Philip D. Reed senior fellow for science and technology at the Council on Foreign Relations, argues that even though reprocessing can help reduce nuclear waste management problems, because as currently practiced it both poses a significant risk that weapons-grade material will fall into the wrong hands and raises the price of nuclear fuel (compared to the once-through fuel cycle), it should not be pursued at present.

As nuclear reactors operate, the nuclei of uranium-235 atoms split, releasing neutrons and nuclei of smaller atoms called fission products, which are themselves radioactive. Some of the neutrons are absorbed by uranium-238, which then becomes plutonium. The fission product atoms eventually accumulate to the point where the reactor fuel no longer releases as much energy as it used to. It is said to be "spent." At this point, the spent fuel is removed from the reactor and replaced with fresh fuel.

Statement before the House Committee on Science, Energy Subcommittee, Hearing on Nuclear Fuel Reprocessing

Summary

Management of spent nuclear fuel from commercial nuclear reactors can be addressed in a comprehensive, integrated manner to enable safe, emissions-free, nuclear electricity to make a sustained and growing contribution to the nation's energy needs. Legislation limits the capacity of the Yucca Mountain repository to 70,000 metric tons from commercial spent fuel and DOE defense-related waste. It is estimated that this amount will be accumulated by approximately 2010 at current generation rates for spent nuclear fuel. To preserve nuclear energy as a significant part of our future energy generating capability, new technologies can be implemented that allow greater use of the repository space at Yucca Mountain. By processing spent nuclear fuel and recycling the hazardous radioactive materials, we can reduce the waste disposal requirements enough to delay the need for a second repository until the next century, even in a nuclear energy growth scenario. Recent studies indicate that such a closed fuel cycle may require only minimal increases in nuclear electricity costs, and are not a major factor in the economic competitiveness of nuclear power (The University of Chicago study, "The Economic Future of Nuclear Power," August 2004). However, the benefits of a closed fuel cycle can not be measured by economics alone; resource optimization and waste minimization are also important benefits. Moving forward in 2007 with an engineering-scale demonstration of an integrated system of proliferation-resistant, advanced separations and transmutation technologies would be an excellent first step in demonstrating all of the necessary technologies for a sustainable future for nuclear energy.

Nuclear Waste and Sustainability

World energy demand is increasing at a rapid pace. In order to satisfy the demand and protect the environment for future generations, energy sources must evolve from the current dominance of fossil fuels to a more balanced,

U.S. House of Representatives, June 16, 2005.

Once removed from the reactor, the spent fuel poses a problem. Currently it is regarded as high-level nuclear waste which must be stored on the site of the reactor, initially in a swimming pool-sized tank and later, once the radioactivity levels have subsided a bit, in "dry casks." Until 2009, there was a plan to dispose of the casks permanently in a subterranean repository being built at Yucca Mountain, Nevada, but the Obama administration has proposed ending funding for Yucca Mountain (see Dan Charles, "A Lifetime of Work Gone to Waste?" *Science*, March 20, 2009).

It is worth noting that spent fuel still contains useful components. Not all the uranium-235 has been burned up, and the plutonium created as fuel is burned, which can itself be used as fuel. When spent fuel is treated as waste, these components of the waste are discarded. Early in the Nuclear Age, it was thought that if these components could be recovered, the amount of waste to be disposed could be reduced; the fuel supply could also be extended. In fact, because plutonium is made from otherwise useless uranium-238, new fuel could be created. Reactors designed to maximize plutonium creation, known as "breeder" reactors because they "breed" fuel, were built and are still in use as power plants in Europe. In the U.S., breeder reactors have been built and operated only by the Department of Defense, because plutonium extracted from spent fuel is required for making nuclear bombs. They have not seen civilian use in part because of the fear that bomb-grade material could fall into the wrong hands.

The separation and recycling of unused fuel from spent fuel is known as reprocessing. In the United States, a reprocessing plant operated in West Valley, New York, from 1966 to 1972 (see "Plutonium Recovery from Spent Fuel Reprocessing by Nuclear Fuel Services at West Valley, New York, from 1966 to 1972" (DOE, 1996; <https://www.osti.gov/opennet/forms.jsp?formurl=document/purecov/ntfrepo.html>). After the Nuclear Nonproliferation Treaty went into force in 1970, it became U.S. policy not to reprocess spent nuclear fuel and thereby to limit the availability of bomb-grade material. As a consequence, spent fuel was not recycled; it was regarded as high-level waste to be disposed of, and the waste continued to accumulate.

The Yucca Mountain nuclear waste disposal site has proven to be controversial, and there remains a great deal of resistance to storing waste there. But the need to dispose of nuclear waste is not about to go away, especially if the United States expands its reliance on nuclear power (see Issue 12). This simple truth drives much of the discussion of nuclear fuel reprocessing. In the following selections, Phillip J. Finck argues that by reprocessing spent nuclear fuel, the United States can enable nuclear power to expand its contribution to the nation's energy needs while reducing carbon emissions, nuclear waste, and the need for waste repositories such as Yucca Mountain. Charles D. Ferguson and Philip D. Reed argues that even though reprocessing can help reduce nuclear waste management problems, because as currently practiced it both poses a significant risk that weapons-grade material will fall into the wrong hands and raises the price of nuclear fuel (compared to the once-through fuel cycle), it should not be pursued at present. There is time for further research. Meanwhile, we should concentrate our efforts on safe storage of nuclear wastes.

sustainable approach. This new approach must be based on abundant, clean, and economical energy sources. Furthermore, because of the growing worldwide demand and competition for energy, the United States vitally needs to establish energy sources that allow for energy independence.

Nuclear energy is a carbon-free, secure, and reliable energy source for today and for the future. In addition to electricity production, nuclear energy has the promise to become a critical resource for process heat in the production of transportation fuels, such as hydrogen and synthetic fuels, and desalinated water. New nuclear plants are imperative to meet these vital needs.

To ensure a sustainable future for nuclear energy, several requirements must be met. These include safety and efficiency, proliferation resistance, sound nuclear materials management, and minimal environmental impacts. While some of these requirements are already being satisfied, the United States needs to adopt a more comprehensive approach to nuclear waste management. The environmental benefits of resource optimization and waste minimization for nuclear power must be pursued with targeted research and development to develop a successful integrated system with minimal economic impact. Alternative nuclear fuel cycle options that employ separations, transmutation, and refined disposal (e.g., conservation of geologic repository space) must be contrasted with the current planned approach of direct disposal, taking into account the complete set of potential benefits and penalties. In many ways, this is not unlike the premium homeowners pay to recycle municipal waste.

The spent nuclear fuel situation in the United States can be put in perspective with a few numbers. Currently, the country's 103 commercial nuclear reactors produce more than 2000 metric tons of spent nuclear fuel per year (masses are measured in heavy metal content of the fuel, including uranium and heavier elements). The Yucca Mountain repository has a legislative capacity of 70,000 metric tons, including spent nuclear fuel and DOE defense-related wastes. By approximately 2010 the accumulated spent nuclear fuel generated by these reactors and the defense-related waste will meet this capacity, even before the repository starts accepting any spent nuclear fuel. The ultimate technical capacity of Yucca Mountain is expected to be around 120,000 metric tons, using the current understanding of the Yucca Mountain site geologic and hydrologic characteristics. This limit will be reached by including the spent fuel from current reactors operating over their lifetime. Assuming nuclear growth at a rate of 1.8% per year after 2010, the 120,000 metric ton capacity will be reached around 2030. At that projected nuclear growth rate, the U.S. will need up to nine Yucca Mountain-type repositories by the end of this century. Until Yucca Mountain starts accepting waste, spent nuclear fuel must be stored in temporary facilities, either storage pools or above ground storage casks.

Today, many consider repository space a scarce resource that should be managed as such. While disposal costs in a geologic repository are currently quite affordable for U.S. electric utilities, accounting for only a few percent of the total cost of electricity, the availability of U.S. repository space will likely remain limited.

Only three options are available for the disposal of accumulating nuclear fuel:

- Build more ultimate disposal sites like Yucca Mountain.
- Use interim storage technologies as a temporary solution.
- Develop and implement advanced fuel cycles, consisting of separation technologies that separate the constituents of spent nuclear fuel into elemental streams, and transmutation technologies that destroy selected elements and greatly reduce repository needs.

A responsible approach to using nuclear power must always consider its whole life cycle, including final disposal. We consider that temporary solutions, while useful as a stockpile management tool, can never be considered as ultimate solutions. It seems prudent that the U.S. always have at least one set of technologies available to avoid expanding geologic disposal sites.

Spent Nuclear Fuel

The composition of spent nuclear fuel poses specific problems that make its ultimate disposal challenging. Fresh nuclear fuel is composed of uranium dioxide (about 96% U238, and 4% U235). During irradiation, most of the U235 is fissioned, and a small fraction of the U238 is transmuted into heavier elements (known as "transuranics"). The spent nuclear fuel contains about 93% uranium (mostly U238), about 1% plutonium, less than 1% minor actinides (neptunium, americium, and curium), and 5% fission products. Uranium, if separated from the other elements, is relatively benign, and could be disposed of as low-level waste or stored for later use. Some of the other elements raise significant concerns:

- The fissile isotopes of plutonium, americium, and neptunium are potentially usable in weapons and, therefore, raise proliferation concerns. Because spent nuclear fuel is protected from theft for about one hundred years by its intense radioactivity, it is difficult to separate these isotopes without remote handling facilities.
- Three isotopes, which are linked through a decay process (Pu241, Am241, and Np237), are the major contributors to the estimated dose for releases from the repository, typically occurring between 100,000 and 1 million years, and also to the long-term heat generation that limits the amount of waste that can be placed in the repository.
- Certain fission products (cesium, strontium) are major contributors to the repository's short-term heat load, but their effects can be mitigated by providing better ventilation to the repository or by providing a cooling-off period before placing them in the repository.
- Other fission products (Tc99 and I129) also contribute to the estimated dose.

The time scales required to mitigate these concerns are daunting: several of the isotopes of concern will not decay to safe levels for hundreds of thousands of years. Thus, the solutions to long-term disposal of spent nuclear fuel are limited to three options: the search for a geologic environment that

will remain stable for that period; the search for waste forms that can contain these elements for that period; or the destruction of these isotopes. These three options underlie the major fuel cycle strategies that are currently being developed and deployed in the U.S. and other countries.

Options for Disposing of Spent Nuclear Fuel

Three options are being considered for disposing of spent nuclear fuel: the once-through cycle is the U.S. reference; limited recycle has been implemented in France and elsewhere and is being deployed in Japan; and full recycle (also known as the closed fuel cycle) is being researched in the U.S., France, Japan, and elsewhere.

1. Once-through Fuel Cycle

This is the U.S. reference option where spent nuclear fuel is sent to the geologic repository that must contain the constituents of the spent nuclear fuel for hundreds of thousands of years. Several countries have programs to develop these repositories, with the U.S. having the most advanced program. This approach is considered safe, provided suitable repository locations and space can be found. It should be noted that other ultimate disposal options have been researched (e.g., deep sea disposal; boreholes and disposal in the sun) and abandoned. The challenges of long-term geologic disposal of spent nuclear fuel are well recognized, and are related to the uncertainty about both the long-term behavior of spent nuclear fuel and the geologic media in which it is placed.

2. Limited Recycle

Limited recycle options are commercially available in France, Japan, and the United Kingdom. They use the PUREX process, which separates uranium and plutonium, and directs the remaining transuranics to vitrified waste, along with all the fission products. The uranium is stored for eventual reuse. The plutonium is used to fabricate mixed-oxide fuel that can be used in conventional reactors. Spent mixed-oxide fuel is currently not reprocessed, though the feasibility of mixed-oxide reprocessing has been demonstrated. It is typically stored or eventually sent to a geologic repository for disposal. Note that a reactor partially loaded with mixed-oxide fuel can destroy as much plutonium as it creates. Nevertheless, this approach always results in increased production of americium, a key contributor to the heat generation in a repository. This approach has two significant advantages:

- It can help manage the accumulation of plutonium.
- It can help significantly reduce the volume of spent nuclear fuel (the French examples indicate that volume decreases by a factor of 4).

Several disadvantages have been noted:

- It results in a small economic penalty by increasing the net cost of electricity a few percent.

- The separation of pure plutonium in the PUREX process is considered by some to be a proliferation risk; when mixed-oxide use is implemented, this material is stored for future use as fuel.
- This process does not significantly improve the use of the repository space (the improvement is around 10%, as compared to a factor of 100 for closed fuel cycles).
- This process does not significantly improve the use of natural uranium (the improvement is around 15%, as compared to a factor of 100 for closed fuel cycles).

3. Full Recycle (the Closed Fuel Cycle)

Full recycle approaches are being researched in France, Japan, and the United States. This approach typically comprises three successive steps: an advanced separations step based on the UREX+ technology that mitigates the perceived disadvantages of PUREX, partial recycle in conventional reactors, and closure of the fuel cycle in fast reactors.

The first step, UREX+ technology, allows for the separations and subsequent management of highly pure product streams. These streams are:

- Uranium, which can be stored for future use or disposed of as low-level waste.
- A mixture of plutonium and neptunium, which is intended for partial recycle in conventional reactors followed by recycle in fast reactors.
- Separated fission products intended for short-term storage, possibly for transmutation, and for long-term storage in specialized waste forms.
- The minor actinides (americium and curium) for transmutation in fast reactors.

The UREX+ approach has several advantages:

- It produces minimal liquid waste forms, and eliminates the issue of the "waste tank farms."
- Through advanced monitoring, simulation and modeling, it provides significant opportunities to detect misuse and diversion of weapons-usable materials.
- It provides the opportunity for significant cost reduction.
- Finally and most importantly, it provides the critical first step in managing all hazardous elements present in the spent nuclear fuel.

The second step—partial recycle in conventional reactors—can expand the opportunities offered by the conventional mixed-oxide approach. In particular, it is expected that with significant R&D effort, new fuel forms can be developed that burn up to 50% of the plutonium and neptunium present in spent nuclear fuel. (Note that some studies also suggest that it might be possible to recycle fuel in these reactors many times—i.e., reprocess and recycle the irradiated advanced fuel—and further destroy plutonium and neptunium; other studies also suggest possibilities for transmuting americium in these reactors. Nevertheless, the practicality of these schemes is not yet established and requires additional scientific

and engineering research.) The advantage of the second step is that it reduces the overall cost of the closed fuel cycle by burning plutonium in conventional reactors, thereby reducing the number of fast reactors needed to complete the transmutation mission of minimizing hazardous waste. This step can be entirely bypassed, and all transmutation performed in advanced fast reactors, if recycle in conventional reactors is judged to be undesirable.

The third step, closure of the fuel cycle using fast reactors to transmute the fuel constituents into much less hazardous elements, and pyroprocessing technologies to recycle the fast reactor fuel, constitutes the ultimate step in reaching sustainable nuclear energy. This process will effectively destroy the transuranic elements, resulting in waste forms that contain only a very small fraction of the transuranics (less than 1%) and all fission products. These technologies are being developed at Argonne National Laboratory and Idaho National Laboratory, with parallel development in Japan, France, and Russia. The full recycle approach has significant benefits:

- It can effectively increase use of repository space by a factor of more than 100.
- It can effectively increase the use of natural uranium by a factor of 100.
- It eliminates the uncontrolled buildup of all isotopes that are a proliferation risk.
- The fast reactors and the processing plant can be deployed in small co-located facilities that minimize the risk of material diversion during transportation.
- The fast reactor does not require the use of very pure weapons usable materials, thus increasing their proliferation resistance.
- It finally can usher the way towards full sustainability to prepare for a time when uranium supplies will become increasingly difficult to ensure.
- These processes would have limited economic impact; the increase in the cost of electricity would be less than 10% (ref: OECD).
- Assuming that demonstrations of these processes are started by 2007, commercial operations are possible starting in 2025; this will require adequate funding for demonstrating the separations, recycle, and reactor technologies.
- The systems can be designed and implemented to ensure that the mass of accumulated spent nuclear fuel in the U.S. would always remain below 100,000 metric tons—less than the technical capacity of Yucca Mountain—thus delaying, or even avoiding, the need for a second repository in the U.S.

Conclusion

A well engineered recycling program for spent nuclear fuel will provide the United States with a long-term, affordable, carbon-free energy source with low environmental impact. This new paradigm for nuclear power will allow us to manage nuclear waste and reduce proliferation risks while creating a sustainable energy supply. It is possible that the cost of recycling will be slightly higher than direct disposal of spent nuclear fuel, but the nation will only need one geologic repository for the ultimate disposal of the residual waste.

An Assessment of the Proliferation Risks of Spent Fuel Reprocessing and Alternative Nuclear Waste Management Strategies

U.S. leadership is essential for charting a constructive and cooperative international course to prevent nuclear proliferation. An essential aspect of that leadership involves U.S. policy on reprocessing spent nuclear fuel. The United States has sought to prevent the spread of reprocessing facilities to other countries and to encourage countries with existing stockpiles of separated plutonium from reprocessing facilities to draw down those stockpiles. The previous administration launched the Global Nuclear Energy Partnership (GNEP), which proposed offering complete nuclear fuel services, including provision of fuel and waste management, from fuel service states to client states in order to discourage the latter group from enriching uranium or reprocessing spent nuclear fuel—activities that would contribute to giving these countries latent nuclear weapons programs. The current administration and the Congress seek to determine the best course for U.S. nuclear energy policy with the focus of this hearing on recycling or reprocessing of spent fuel and nuclear waste management strategies.

Here at the start, I give a brief summary of the testimony's salient points:

- Reprocessing of the type currently practiced in a handful of countries poses a significant proliferation threat because of the separation of plutonium from highly radioactive fission products. A thief, if he had access, could easily carry away separated plutonium. Fortunately, this reprocessing is confined to nuclear-armed states except for Japan. If this practice spreads to other non-nuclear-weapon states the consequences for national and international security could be dire. Presently, the vast majority of the 31 states with nuclear power programs do not have reprocessing plants.
- The types of reprocessing examined under GNEP do not appear to offer substantial proliferation-resistant benefits, according to research sponsored by the Department of Energy. However, more research is needed to determine what additional safeguards, if any, could provide greater assurances that reprocessing methods are not misused in weapons

U.S. Senate, June 17, 2009.

programs and whether it is possible to have assurances of timely detection of a diversion of a significant quantity of plutonium or other fissile material.

- Time is on the side of the United States. There is no need to rush toward development and deployment of recycling of spent nuclear fuel. Based on the foreseeable price for uranium and uranium enrichment services, this practice is presently far more expensive than the once-through uranium fuel cycle. Nonetheless, more research is needed to determine the costs and benefits of recycling techniques coupled with fast-neutron reactors or other types of reactor technologies. This cost versus benefit analysis would concentrate on the capability of these technologies to help alleviate the nuclear waste management challenge.
- In related research, there is a need to better understand the safeguards challenges in the use of fast reactors. Such reactors are dual-use in the sense that they can burn transuranic material and can breed new plutonium. In the former operation, they could provide a needed nuclear waste management benefit. In the latter operation, they can pose a serious proliferation threat.

Proliferation Risks

Reprocessing involves extraction of plutonium and/or other fissile materials from spent nuclear fuel in order to recycle these materials into new fuel for nuclear reactors. As discussed below, many reprocessing techniques are available for use. Regardless of the particular technique, fissile material is removed from all or almost all of the highly radioactive fission products, which provide a protective barrier against theft or diversion of plutonium in spent nuclear fuel. Plutonium-239 is the most prevalent fissile isotope of plutonium in spent nuclear fuel. The greater the concentration of this isotope the more weapons-usable is the plutonium mixture. Weapons-grade plutonium typically contains greater than 90 percent plutonium-239 whereas reactor-grade plutonium from commercial thermal-neutron reactors has usually less than 60 percent plutonium-239, depending on the characteristics of the reactor that produced the plutonium. The presence of non-plutonium-239 isotopes complicates production of nuclear weapons from the plutonium mixture, but the challenges are surmountable.¹ According to an unclassified U.S. Department of Energy report, reactor-grade plutonium is weapons-usable.²

The potential proliferation threats from reprocessing of spent nuclear fuel are twofold. First, a state operating a reprocessing plant could use that technology to divert weapons-usable fissile material into a nuclear weapons program or alternatively it could use the skills learned in operating that plant to build a clandestine reprocessing plant to extract fissile material. Second, a non-state actor such as a terrorist group could seize enough fissile material produced by a reprocessing facility in order to make an improvised nuclear device—a crude, but devastating, nuclear weapon. Such a non-state group may obtain help from insiders at the facility. While commercial reprocessing facilities have typically been well-guarded, some facilities such as those at Sellafield in the United Kingdom and Tokai-mura in Japan have not been able to account for

several weapons' worth of plutonium. This lack of accounting does not mean that the fissile material was diverted into a state-sponsored program. The discrepancy was most likely due to plutonium theft. But an insider could exploit such a discrepancy. For commercial facilities, several tons of plutonium can be processed annually, one tenth of one percent of this material were accounted for, conceivably divert about one weapon's worth of plutonium even.

Location matters when determining the proliferation risk in a reprocessing program. That is, a commercial reprocessing plant in a nuclear state such as France, Russia, or the United Kingdom poses no risk of state access (but could pose a risk of non-state access) because this type of state access, already has a weapons program. Notably, Japan is the only non-nuclear armed state that has reprocessing facilities. Japan has applied the Additional Protocol to its International Atomic Energy Agency safeguards, but its stockpile of reactor-grade plutonium could provide a significant breakout capability for a weapons program. (Chinese officials and analysts occasionally express concern about Japan's plutonium stockpile.) Since the Ford and Carter administrations, when the United States decided against reprocessing on proliferation and economic grounds, the United States has made stopping the spread of further reprocessing facilities especially to non-nuclear weapon states a top priority.

Another top priority of U.S. policy on reprocessing is to encourage countries with stockpiles of separated plutonium to draw down these stockpiles quickly. This drawdown can be done either through consuming the plutonium as fuel or surrounding it with highly radioactive fission products. Global stockpiles of civilian plutonium are growing and now at about 250 metric tons—equivalent to tens of thousands of nuclear bombs—are comparable to the global stockpile of military plutonium. More than 1,000 metric tons of plutonium is contained in spent nuclear fuel in about thirty countries.

While no country has used a commercial nuclear power program to make plutonium for nuclear weapons, certain countries have used research reactor programs to produce plutonium. India, notably, used a research reactor supplied by Canada to produce plutonium for its first nuclear explosive device in 1974. North Korea, similarly, has employed a research-type reactor to produce plutonium for its weapons program. Although nonproliferation efforts to prevent Iran has focused on its uranium enrichment program, which could make fissile material for weapons, its construction of a heavy water research reactor, which when operational (perhaps early next decade) could produce at least one weapon's worth of plutonium annually, poses a latent proliferation threat. To date, Iran is not known to have constructed a reprocessing facility that would be needed to extract plutonium from this reactor's spent fuel. Further activities could take place in the Middle East and other regions. For instance, according to the U.S. government, Syria received assistance from North Korea in building a plutonium production reactor. In September 2009, Israel bombed this construction site.

The United States has been trying to balance the perceived need by many states in the Middle East for nuclear power plants versus restricting these states'

access to enrichment and reprocessing technologies. Presently, as an outstanding example, the U.S.-UAE bilateral nuclear cooperation agreement is before the U.S. Congress. Proponents of this agreement tout the commitment made by the UAE to refrain from acquiring enrichment and reprocessing technologies and to rely on market mechanisms to purchase nuclear fuel. However, the last clause in the agreement appears to open the door for the UAE to engage in such activities in the future:

EQUAL TERMS AND CONDITIONS FOR COOPERATION

The Government of the United States of America confirms that the fields of cooperation, terms and conditions accorded by the United States of America to the United Arab Emirates for cooperation in the peaceful uses of nuclear energy shall be no less favorable in scope and effect than those which may be accorded, from time to time, to any other non-nuclear-weapon State in the Middle East in a peaceful nuclear cooperation agreement. If this is, at any time, not the case, at the request of the Government of the United Arab Emirates the Government of the United States of America will provide full details of the improved terms agreed with another non-nuclear-weapon State in the Middle East, to the extent consistent with its national legislation and regulations and any relevant agreements with such other non-nuclear-weapon State, and if requested by the Government of the United Arab Emirates, will consult with the Government of the United Arab Emirates regarding the possibility of amending this Agreement so that the position described above is restored.³

Such a request for amendment could be around the corner because Jordan is seeking to conclude a bilateral nuclear cooperation agreement with the United States, and it has expressed interest in keeping open the option to enrich uranium. Jordan has discovered large quantities of indigenous uranium and may want to "add value" to that uranium through enrichment. Jordan or any other Middle Eastern state has not yet expressed interest in reprocessing. U.S. leadership and practice in this issue will serve as an example for other states interested in acquiring new nuclear power programs.

Proliferation-Resistant Reprocessing

Can reprocessing be made more proliferation-resistant? "Proliferation resistance is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the host state seeking to acquire nuclear weapons or other nuclear explosive devices."⁴ No nuclear energy system is proliferation proof because nuclear technologies are dual-use. Enrichment and reprocessing can be used either for peaceful or military purposes. However, through a defense-in-depth approach, greater proliferation resistance may be achieved. Both intrinsic features (for example, physical and engineering characteristics of a nuclear technology) and extrinsic features (for example, safeguards and physical barriers) complement each other to deter misuse of nuclear technologies and materials in weapons programs. The potential threats that proliferation-resistance tries to guard against are:

- "Concealed diversion of declared materials;
- Concealed misuse of declared facilities;
- Overt misuse of facilities or diversion of declared materials; and
- Clandestine declared facilities."⁵

For each of these threats, a detailed proliferation pathway analysis can be done in order to measure the proliferation risk and to determine the needed, if any, additional safeguards. The U.S. Department of Energy has sponsored such analysis for proposed reprocessing techniques considered under GNEP.⁶ These techniques include UREX+, COEX, NUX, and Pyroprocessing, and they have been compared to the PUREX technique, which is the commercially used method. PUREX separates plutonium and uranium from highly radioactive fission products. It is an aqueous separations process and thus generates sizable amounts of liquid radioactive waste. UREX+, COEX, and NUX are also aqueous processes. UREX+ is a suite of chemical processes in which pure plutonium is not separated but different product streams can be produced depending on the reactor fuel requirements. COEX and NUX are related processes. COEX co-extracts uranium and plutonium (and possibly neptunium) into one recycling stream; another stream contains pure uranium, which can be recycled; and a final stream contains fission products. NUX separates into three streams: uranium, transuranics (including plutonium), and fission products. Pyroprocessing uses electrorefining techniques to extract plutonium in combination with other transuranic elements, some of the rare earth fission products, and uranium. This fuel mixture would be intended for use in fast-neutron reactors, which have yet to be proven commercially viable.

Can these reprocessing techniques meet the highest proliferation resistance standard of the "spent fuel standard" in which plutonium in its final form should be as hard to acquire, process, and use in weapons as is plutonium embedded in spent fuel?⁷ The brief answer is "no" because the act of separating most or all of the highly radioactive fission products makes the fuel product less protected than the intrinsic protection provided by spent fuel. In fact, Dr. E.D. Collins of Oak Ridge National Laboratory has shown that the radiation emission from these reprocessed products is 100 times less than the spent fuel standard.⁸ In other words, a thief could carry these products and not suffer a lethal radiation dose whereas the same thief would experience a lethal dose in less than one hour of exposure to plutonium surrounded by highly radioactive fission products. But these methods may still be worth pursuing depending on a detailed systems analysis factoring in security risks on site and during transportation, the final disposition of the material once it has been recycled as fuel, as well as the costs and benefits of nuclear waste management.

According to DOE's draft nonproliferation assessment of GNEP, "for a state with preexisting PUREX or equivalent capability (or more broadly the capability to design and operate a reprocessing plant of this complexity), there is minimal proliferation resistance to be found by [using the examined reprocessing techniques] considering the potential for diversion, misuse, and breakout scenarios."⁹ Moreover, the DOE assessment points out that these techniques pose additional safeguards challenges. For example, it is difficult

to do an accurate accounting of the amount of plutonium in a bulk handling reprocessing facility that produces plutonium mixed with other transuranic elements.¹⁰ This challenge raises the probability of diversion of plutonium by insiders.¹¹

Another set of considerations is the choice of reactors to burn up the transuranic elements. The DOE draft assessment examined several choices including light water reactors, heavy water reactors, high temperature gas reactors, and fast-neutron reactors. Only the fast-neutron reactors offered the most benefits in terms of net consumption of transuranic material. This material would have to be recycled multiple times in fast reactors to consume almost all of it. This is called a full actinide recycle in contrast to a partial actinide recycle with the other reactor methods. The benefit from a waste management perspective is that the amount of time required for spent fuel's radiotoxicity to reduce to that of natural uranium goes from more than tens of thousands of years for partial actinide recycle to about 400 years for the full actinide recycle.

The challenge of the full actinide route, however, is that fast reactors can relatively easily be changed from a burner mode to a breeder mode. That is, these reactors can breed more plutonium by the insertion of uranium target material. The perceived need for breeder reactors has driven a few countries such as France, India, Japan, and Russia to develop reprocessing programs.

Alternative Nuclear Waste Management Programs of Other Nations

Has reprocessing programs, to date, helped certain nations solve their nuclear waste problems? The short answer is, "no." Before explicating that further, it is worth briefly examining why these countries began these programs. About fifty years ago, when the commercial nuclear industry was just starting, concerns were raised about the availability of enough natural uranium to fuel the thousands of reactors that were anticipated. Natural uranium contains 0.71 percent uranium-235, 99.28 percent uranium-238, and less than 0.1 percent uranium-234. Uranium-235 is the fissile isotope and thus is needed for sustaining a chain reaction. However, uranium-238 is a fertile isotope and can be used to breed plutonium-239, a fissile isotope that does not occur naturally. Thus, if uranium-238 can be transformed into plutonium-239, the available fissile material could be expanded by more than one hundred times, in principle. This observation motivated several countries, including the United States, to pursue reprocessing.

A related motivation was the desire for better energy security and thus less dependence on outside supplies of uranium. France and Japan, in particular, as countries with limited uranium resources, developed reprocessing plants in order to try to alleviate their dependency on external sources of uranium. They had invested in these plants before the realization that the world would not run out of uranium soon. By the late 1970s, two developments happened that alleviated the perceived pending shortfall. First, the pace of proposed nuclear power

plant deployments dramatically slowed. There were plans at that time for more than 1,000 large reactors (of about 1,000 MWe power rating) by 2000, but even before the Three Mile Island accident in 1979, the number of reactor orders in the United States and other countries slackened off although France and Japan launched a reactor building boom in the 1970s that lasted through the 1980s. By 2000, there was only the equivalent of about 400 reactors of 1,000 MWe size. Second, uranium prospecting identified enough proven reserves to supply the present nuclear power demand for several decades to come.

Because there is plentiful uranium at relatively low prices and the cost of uranium enrichment has decreased, the cost of the once-through uranium cycle is significantly less than the cost of reprocessing. However, because fuel costs are a relatively small portion of the total costs of a nuclear power plant, reprocessing adds a relatively small amount to the total cost of electricity. In France, the added cost is almost six percent, and in Japan about ten percent. Nonetheless, in competitive utility markets in which consumers have choices, most countries have not chosen the reprocessing route because of the significantly greater fuel costs. France and Japan have adopted government policies in favor of reprocessing and also have sunk many billions of dollars into their reprocessing facilities. The French government owns and controls the electric utility Electricité de France (EDF) and the nuclear industry Areva. Despite this extensive government control, a 2000 French government study determined that if France stops reprocessing, it would save \$4 to \$5 billion over the remaining life of its reactor fleet.¹² EDF assigns a negative value to recycled plutonium.

While France's La Hague plant is operating, Japan is still struggling to start up its Rokkasho plant, which is largely based on the French design. Thus, the costs of the Japanese plant keep climbing and will likely be more than \$20 billion. While the Japanese government wants to fuel up to one-third of its more than 50 reactors with plutonium-based mixed oxide fuel, local governments tend to look unfavorably on this proposal.

Only a few other nations are involved with reprocessing. Russia and the United Kingdom operate commercial-scale facilities. China and India are interested in heading down this path. But the United Kingdom is moving toward imminent shut down of its reprocessing mainly due to lack of customers. Moreover, the clean up and decommissioning costs are projected to be many billions of dollars. Russia and France also lack enough customers to keep their reprocessing plants at full capacity. In early April, I visited the French La Hague plant and was told that it is only operating at about half capacity. France only uses mixed oxide fuel in 20 of its 58 light water reactors. Presently, less than 10 percent of the world's commercial nuclear power plants burn MOX fuel. As stated earlier, the demand for MOX fuel has not kept up with the stockpiled quantities of plutonium.

With respect to nuclear waste management, an important point is that reprocessing, as currently practiced, does little or nothing to alleviate this management problem. For example, France practices a once-through recycling in which plutonium is separated once, made into MOX fuel, and the spent fuel containing this MOX is not usually recycled once (although France has

done some limited recycling of MOX spent fuel). The MOX spent fuel is stored pending the further development and commercialization of fast reactors. But France admits that this full deployment of a fleet of fast reactors is projected to take place at the earliest by mid-century. France will shut down later this year its only fast reactor, the prototype Phénix. Perhaps around 2020, France may have constructed another fast reactor, but the high costs of these reactors have been prohibitive. In effect, France has shifted its nuclear waste problem from the power plants to the reprocessing plant.

France's practice of transporting plutonium hundreds of miles from the La Hague to the MOX plant at Marcoule poses a security risk. While there has never been a theft of plutonium or a major accident during the hundreds of trips to date, each shipment contains many weapons' worth of plutonium. Thus, just one theft of a shipment could be an international disaster.

No country has yet to open a permanent repository. But the country with the most promising record of accomplishment in this area is Sweden. A couple of weeks ago, Sweden announced the selection of its repository site but admits that the earliest the site will accept spent fuel is 2023. Sweden had carefully evaluated three different sites and obtained widespread community and local government involvement in the decision making process. France touts the benefits of the volume reduction of recycling in which highly radioactive fission products are formed into a glass-like compound, which is now stored at an interim storage site. By weight percentage, spent fuel typically consists of 95.6% uranium (with most of that being uranium-238), 3% stable or short-lived radioactive fission products, 0.3% cesium and strontium (the primary sources of high-level radioactive waste over a few hundred years), 0.1% long-lived iodine and technetium, 0.1% long-lived actinides (heavy radioactive elements), and 0.9% plutonium. But the critical physical factor for a repository is the heat load. For the first several hundred years of a repository the most heat emitting elements are the highly radioactive fission products. The benefit of a fast reactor recycling program could be the reduction or near elimination of the longer-lived transuranic elements that are the major heat producing elements beyond several hundred years.

Other countries may venture into reprocessing. Therefore, it is imperative for the United States to reevaluate its policies and redouble its efforts to prevent the further spread of reprocessing plants to non-nuclear-weapon states. In particular, the Republic of Korea is facing a crisis in the overcrowded conditions in the spent fuel pools at its power plants. One option is to remove older spent fuel and place it in dry storage casks, but the ROK government believes this option may cost too much because of the precedent set by the exorbitantly high price paid for a low level waste disposal facility. Another option is for the ROK to reprocess spent fuel. While this will provide significant volume reduction in the waste, it will only defer the problem to storage of MOX spent fuel, similar to the problem faced by France. This option will run counter to the agreement the ROK signed with North Korea in the early 1990s for both states to prohibit reprocessing or enrichment on the Korean Peninsula. A related option is to ship spent fuel to La Hague, but a security question is whether to ship plutonium back to the ROK. France would require

shipment of the high level waste back to the ROK. Thus, the ROK will need a high level waste disposal facility. The main reason I raise this ROK issue at length is that the ROK and the United States have recently begun talks on the renewal of their peaceful nuclear cooperation agreement, which will expire in 2014. The United States has consent rights on ROK spent fuel because either it was produced with U.S.-supplied fresh fuel or U.S.-origin reactor systems. The ROK is seeking to have future spent fuel not subject to such consent rights by purchasing fresh fuel from other suppliers and by developing reactor systems that do not have critical components that are U.S.-origin or derived from U.S.-origin systems. The bottom line is that the United States is steadily losing its leverage with the ROK and other countries because of declining U.S. leadership in nuclear power plant systems and nuclear waste management.

Concerning lessons the United States can learn from other countries' nuclear waste management experience, the first lesson is that a fair political and sound scientific process is essential for selecting a permanent repository. Sweden demonstrates the effectiveness of examining multiple sites and gaining buy-in from the public and local governments. The second lesson is that reprocessing, as currently practiced, does not substantially alleviate the nuclear waste management problem. However, more research is needed to determine the costs and benefits of fast reactors for reducing transuranic waste. Any type of reprocessing will require safe and secure waste repositories.

While the United States investigates the costs and benefits of various recycling proposals through a research program, it has an opportunity now to exercise leadership in two waste management areas. First, as envisioned in GNEP, the United States should offer fuel leasing services. As part of those services, it should offer to take back spent fuel from the client countries. (Russia is offering this service to Iran's Bushehr reactor.) This spent fuel does not necessarily have to be sent to the United States. It could be sent to a third party country or location that could earn money for the spent fuel storage rental service. Spent fuel can be safely and securely stored in dry storage casks for up to 100 years. Long before this time ends, a research program will most likely determine effective means of waste management. The spent fuel leasing could be coupled to the second area where the United States can play a leadership role. That is, the United States can offer technical expertise and political support in helping to establish regional spent fuel repositories. A regional storage system would be especially helpful for countries with smaller nuclear power programs.

Recommendations

- Continue to discourage separation of plutonium from spent nuclear fuel.
- Limit the spread of reprocessing technologies to non-nuclear weapon states.
- Draw down the massive stockpile of civilian plutonium.
- Support a research program to assess the costs and benefits of various reprocessing technologies with attention focused on proliferation-resistance, safeguards, and nuclear waste management. Compare the

costs and benefits of reprocessing to enrichment, factoring in the proliferation risks of both technologies.

- Increase funding for safeguards research.
- Promote safe and secure storage of spent fuel until the time when reprocessing may become economically attractive.
- Evaluate multiple sites for permanent waste repositories based on political fairness and sound scientific assessments. Obtain buy-in from the public and local governments.
- Use secure interim spent fuel storage employing dry storage casks to relieve build up on spent fuel pools.
- Provide fuel leasing services that would include take back of spent fuel to either the fuel supplier state or a third party.
- Develop regional spent fuel storage facilities.
- Obtain better estimates on the remaining global reserves of uranium.
- Provide research support for developing more efficient nuclear power plants that would produce more electrical power per thermal power than today's fleet of reactors. Similarly, research more effective ways to make more efficient use of uranium fuel and reduce the amounts of plutonium-239 produced.

Notes

1. Richard L. Garwin, "Reactor-Grade Plutonium Can Be Used to Make Powerful and Reliable Nuclear Weapons," Paper for the Council on Foreign Relations, August 26, 1998. J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science and Global Security*, 4, 111-128, 1993.
2. *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material and Excess Plutonium Disposition Alternatives*, DOE/NN-0007 (Washington, DC: U.S. Department of Energy, January 1997), pp. 38-39.
3. Agreement for Cooperation between the Government of the United States of America and the Government of the United Arab Emirates Concerning Peaceful Uses of Nuclear Energy, May 21, 2009.
4. Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008, p. 26.
5. *Ibid.*, p. 28.
6. See, for example, many of the references cited in Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008.
7. Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Washington, DC: National Academy Press, 1994.
8. E.D. Collins, Oak Ridge National Laboratory, "Closing the Fuel Cycle Can Extend the Lifetime of the High-Level Waste Repository," American Nuclear Society 2005 Winter Meeting, November 17, 2005, p. 13.

9. *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives*, p. 69.
10. J.E. Stewart et al., "Measurement and Accounting of the Minor Actinides Produced in Nuclear Power Reactors," Los Alamos National Laboratory, LA-13054-MS, January 1996, p. 21.
11. Ed Lyman, "U.S. Nuclear Fuel Reprocessing Initiative: DOE Research Shows Technology Does Not Reduce Risks of Nuclear Proliferation and Terrorism," Fact Sheet, Union of Concerned Scientists, February 2006.
12. *Economic Forecast Study of the Nuclear Option* (Planning Commission, Government of France, 2000), section 3.4.



POSTSCRIPT

Should the United States Reprocess Spent Nuclear Fuel?

The nuclear waste disposal problem is real and it must be dealt with. If it is not, we may face the same kinds of problems created by the former Soviet Union, which disposed of some nuclear waste simply by dumping it at sea. For a summary of the nuclear waste problem and the disposal controversy, see Michael E. Long, "Half Life: The Lethal Legacy of America's Nuclear Waste," *National Geographic* (July 2002). The need for care in nuclear waste disposal is underlined by Tom Carpenter and Clare Gilbert, "Don't Breathe the Air," *Bulletin of the Atomic Scientists* (May/June 2004); they describe the Hanford Site in Hanford, Washington, where wastes from nuclear weapons production were stored in underground tanks. Leaks from the tanks have contaminated groundwater, and an extensive cleanup program is under way. But cleanup workers are being exposed to both radioactive materials and toxic chemicals, and they are falling ill. And in June 2004, the U.S. Senate voted to ease cleanup requirements. Per F. Peterson, William E. Kastenberger, and Michael Corradini, "Nuclear Waste and the Distant Future," *Issues in Science and Technology* (Summer 2006), argue that the risks of waste disposal have been sensibly addressed and we should be focusing more attention on other risks (such as those of global warming). Behnam Taebi and Jan Kloosterman, "To Recycle or Not to Recycle? An Intergenerational Approach to Nuclear Fuel Cycles," *Science & Engineering Ethics* (June 2008), argue that the question of whether to accept reprocessing comes down to choosing between risks for the present generation and risks for future generations.

In November 2005, President Bush signed the budget for the Department of Energy, which contained \$50 million to start work toward a reprocessing plant; see Eli Kintisch, "Congress Tells DOE to Take Fresh Look at Recycling Spent Reactor Fuel," *Science* (December 2, 2005). By April 2008, Senator Pete Domenici of the U.S. Senate Energy and Natural Resources Committee was working on a bill that would set up the nation's first government-backed commercialized nuclear waste reprocessing facilities. Reprocessing spent nuclear fuel will be expensive, but the costs may not be great enough to make nuclear power unacceptable; see "The Economic Future of Nuclear Power," University of Chicago (August 2004) (<http://www.ne.doe.gov/np2010/reports/NuclIndustryStudy-Summary.pdf>).

In February 2006, the United States Department of Energy announced the Global Nuclear Energy Partnership (GNEP), to be operated by the U.S., Russia, Great Britain, and France. It would lease nuclear fuel to other nations, reprocess spent fuel without generating material that could be diverted to making nuclear bombs, reduce the amount of waste that must be disposed of, and help

meet future energy needs. See Stephanie Cooke, "Just Within Reach," *Bulletin of the Atomic Scientists* (July/August 2006), and Jeff Johnson, "Reprocessing Key to Nuclear Plan," *Chemical & Engineering News* (June 18, 2007), online such as Karen Charman ("Brave Nuclear World, Parts I and II," *World Watch* (May/June and July/August 2006), insist that nuclear power is far too expensive and carries too serious risks of breakdown and exposure to waste to rely upon, especially when cleaner, cheaper, and less dangerous alternatives exist. Early in 2009, the Department of Energy announced it was closing down GNEP.

It is an unfortunate truth that the reprocessing of nuclear spent fuel does indeed increase the risks of nuclear proliferation. Both nations and terrorists it to possess nuclear weapons, whose destructive potential makes present members of the "nuclear club" tremble. Can the risks be controlled? John Deutch, Arnold Kanter, Ernest Moniz, and Daniel Poneman, in "Making the World Safe for Nuclear Energy," *Survival* (Winter 2004/2005), argue that present nuclear nations could supply fuel and reprocess spent fuel for other nations; nations that refuse to participate would be seen as suspect and subject to international action. Nuclear physicist and Princeton professor Frank N. von Hippel, "Rethinking Nuclear Fuel Recycling," *Scientific American* (May 2008) argues that reprocessing nuclear spent fuel is expensive and emits lethal radiation. There is also a worrisome risk that the increased availability of bomb-grade nuclear materials will increase the risk of nuclear war and terrorism. Prudence demands that spent fuel be stored until the benefits of reprocessing exceed the risks (if they ever do).

