U.S. VULNERABILITY TO OIL-PRICE SHOCKS AND SUPPLY CONSTRICTIONS... AND HOW TO REDUCE IT

TESTIMONY OF
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MR. CHAIRMAN, MEMBERS, LADIES AND GENTLEMEN: I am John P. Holdren, a professor at Harvard in both the Kennedy School of Government and the Department of Earth and Planetary Sciences. Since 1996 1 have directed the Kennedy School's Program on Science, Technology, and Public Policy, and for 23 years before that I co-led the interdisciplinary graduate program in Energy and Resources at the University of California, Berkeley. Also germane to today's topic, I am a member of President Clinton's Committee of Advisors on Science and Technology (PCAST) and served as chairman of the 1997 PCAST study of "Federal Energy Research and Development for the Challenges of the 2 1 st Century' 'and the 1999 PCAST study of "Powerful Partnerships: The Federal Role in International Cooperation on Energy Research, Development Demonstration, and Deployment". A more complete biographical sketch is appended to this statement. The opinions I will offer here are my own and not necessarily those of any of the organizations with which I am associated. I very much appreciate the opportunity to testify this morning on this timely and important subject.

The recent run-up of world oil prices and its reverberations in U.S. markets for gasoline and fuel oil underline a degree of U.S. dependence on imported oil - with associated vulnerability to externally induced oil-price shocks and supply constrictions - that has been growing since 1985. In that year, the United States was importing just under 30% of the oil it used, down from the previous all-time peak of 49% reached in 1977. By 1990, our dependence on imports for our oil was back up to 46% - the result of slowly growing national oil consumption and slowly declining domestic production - and by 1998 our oil-import dependence had reached 55%.(*1)

The economic impact of U.S. oil-import dependence is not as great as it was in the late 1970s and early 1980s, however, because the share of oil in our total energy mix has fallen since then,

because the total amount of energy needed to make a dollar of GDP has also fallen, and because the real price of oil, even after,the recent run-up, remains far below what it was then. Oil (domestic plus imported) constituted 46% of U.S. energy supply in 1979 but only 39% in 1999. The amount of energy needed to make an inflation-corrected dollar of GDP in the United States fell by 30% between 1979 and 1999, and the amount of oil per dollar of GDP fell by 40%. The cost of U.S. net oil imports in 1979 was $112 billion (expressed in 1999 dollars) or 2.1 percent of GDP, whereas the corresponding figure in 1999 was $57 billion, amounting to 0.6 percent of GDP.

That the impact of oil-import expenditures on the total U.S. economy is not as great as it once was should not console us much in the current situation, for several reasons. First, as recent events make plain, the impact can still be great in the specific sectors of the economy that remain heavily dependent on oil, most notably the transport sector nationwide and home heating in the Northeast. Second, U.S. dependence on oil imports as a fraction of national energy supply is more than high enough, at around 21 percent, to make the possibility of externally imposed supply constrictions a matter of great concern; indeed, it is seen as imposing requirements on our capacity to defend our access to foreign oil by the use of military force if need be, and hence is a source of military budget requirements as well as a potential source of actual conflict. Third, our 1999 foreign-oil expenditure of 0.6% of GDP is by no means an upper limit: if oil prices stayed near the $34 per barrel figure they reached in early 2000 and U.S. oil imports nonetheless did not decline, U.S. oil-import costs would reach about 1.3% of GDP. Under "business as usual", moreover, U.S. oil imports are projected to continue to rise, and the price per barrel could go up further still.

It must also be a matter of concern for the future that the fractions of U.S. oil imports (and everybody else's) coming from the OPEC cartel and, within it, from the politically volatile Persian Gulf are more likely to increase with time than to decrease. Currently, the United States gets half of its oil imports from OPEC and half of that amount - a quarter overall - from the Persian Gulf. Worldwide, OPEC accounts for 43% of world oil production and 60% of the oil traded internationally, but holds 75% of the world's proved oil reserves. The Persian Gulf alone has some 30% of world production, 45% of exports, and 63% of proved reserves. That OPEC and the Persian Gulf hold larger shares of reserves than of current production and exports means that their shares of production and exports are likely to increase over time. The prospect of increasing dependence on these unpredictable partners for oil imports - and not just by the United States but also by our friends and some of our potential adversaries - is not reassuring in either economic or national-security terms.

The costs and dangers of the overdependence of the United States and others on imported oil are clearly considerable, and they are likely to grow unless successful evasive action is taken. What have we been doing in this direction and what has it accomplished? What more could and should we be doing now and in the future, and what leverage against the problem might these additional measures yield?

The problem of reducing oil imports below what they would otherwise be can be addressed by (1) decreasing oil consumption below what it would otherwise be, (2) increasing domestic oil production above what it would otherwise be., or (of course) a combination of these. Leaving aside the option of reducing economic activity below what it would otherwise he (which would be seen as part of the problem rather than part of the solution), the possibilities for decreasing oil consumption consist of (La) increasing the efficiencies with which oil is converted to end-use forms and used to produce economic goods and services and (Lb) substituting other energy forms for oil. The possibilities for increasing domestic oil production consist of (2.a) finding and developing new oil fields and (2.b) increasing the quantities of oil recovered from existing fields. In all cases, these outcomes can be pursued through a combination of (i) incentives, investments, and other measures that affect the choices made within the available array of technological options and (ii) incentives, investments; and other measures that lead to improvement of the available array of technological options through research, development, and demonstration.

All of these approaches have been employed in varying degrees over the past two decades, and all of them have a role to play in the decades ahead. All of them can and should be strengthened with further policy initiatives. But analysis of recent history and of the prospects for the future indicates that much larger gains are to be expected from reducing consumption through efficiency increases and substitution than from increasing domestic production.

Consider first the history of efficiency increases and substitution. From 1972 (the year before the first Arab-OPEC oil-price shock) until 1979 (the year of the second and larger shock), the energy intensity of the U.S. economy fell at an average rate of 1.7% per year. (Over the preceding 20 years, this figure had fallen at only 0.4% per year.) In this same period, 1972-79, oil's share of total U.S. energy supply did not change. As a very rough approximation, then, one may attribute to price- and policy-induced improvements in overall energy efficiency, following the 1973 shock, the difference between the pre-1972 and 1972-79 rates of change in this index, or 1.7 - 0.4 = 1.3% per year. Over the seven-year period, this would make oil use in 1979 about 9.5 percent lower than it would have been under "business as usual", amounting to a savings of 1.9 million barrels per day.

From 1919 to 1985 Oust before oil prices went into sharp decline), the energy intensity of the U.S. economy fell at an average rate 3.2% per year and oil's share of total U.S. energy supply fell at an average rate of 2.1% per year. By the same procedure as used for the preceding period, this leads to an estimate of additional oil savings in 1985 of 5.5 million barrels per day beyond those achieved by 1979 (and compared to what would have happened under the pre- 1972 business-as-usual trends), resulting from the combination of energy-efficiency improvements and substitution for oil in the period 1979-85. The estimated total reduction in U.S. oil demand in 1985 as a result of price -and policy-induced efficiency improvements and oil substitution after 1972 - compared to what demand would have been if the pre-1972 trends had prevailed for that whole period - then would be 5.5 + 1.9 = 7.4 million barrels per day.

From 1985 to 1999 (a period of generally declining real oil prices), the energy intensity of the U.S. economy fell at an average rate of 1.2% per year, while oil's share in U.S. total energy supply fell hardly at all (average rate of decline 0.2% per year). Estimated additional oil savings over this period, calculated as above by comparison to the pre-1972 rate of decline in energy intensity and constant oil share, would be 2.9 million barrels per day. This means that the total reduction in U.S. oil consumption by 1999, as a result of increased rates of energy-efficiency improvement and of substitution for oil in the U.S. energy mix that followed the oil-price shocks of the 1970s, plausibly amounted to 7.4 + 2.9 = 10.3 million barrels per day.

The effects of price and policy on domestic oil production over the same time period are more difficult to estimate. U.S. domestic production of crude petroleum plus natural gas plant liquids (together characterized as "total petroleum") peaked in 1970 at 11.3 million barrels per day and by 1973 had declined to 11.0 million barrels per day. Notwithstanding the price signals and other incentives to increase domestic production after the first oil-price shock in 1973, domestic production continued to decline through 1976, when it averaged 9.8 million barrels per day. With the help of the ramp-up of production from Alaska's Prudhoe Bay field, it then increased to a secondary peak of 10.6 million barrels per day in 1985, falling more or less steadily thereafter to 8.1 million barrels per day in 1999. (Alaskan production peaked at 2.0 million barrels per day in 1987 and 1988 and has since declined to 1.0 million barrels per day).

Aside from this Alaskan contribution, without which our domestic production today would be 7 million rather than 8 million barrels per day, it is hard to estimate in any simple way the amount by which price- and policy-induced bolstering of domestic production made the decline in domestic production slower than it otherwise would have been. Advances in seismic exploration, horizontal drilling, and secondary recovery are generally mentioned, but it would take a closer student of these matters, than I have been to offer a quantitative estimate of how many barrels per day these advances are currently adding to U.S. production. If they were as much as doubling the current U.S. rate of crude oil production from what it would otherwise be (6 million barrels per day instead of 3 million), their contribution would still be only a third as big as my estimate of the gains from 1972 to 1999 from acceleration of the rate of improvement in energy efficiency and the rate, of substitution for oil in the overall energy mix.

What have been the changes in the U.S. energy-supply mix? The increase in coal consumption from 1972 to 1998 was 9.5 quadrillion Btu per year, equivalent to 4.5 million barrels per day of oil; coal's share of U.S. energy supply increased in this period from 16.6% of the total to 22.9%. U.S. natural gas consumption fell from an all-time high of 22.7 quadrillion Btu per year in 1972 to 16.7 quadrillion Btu per year in 1986, then rose again to 21.8 quadrillion Btu per year in 1998; its share of total U.S. energy supply was 31.2% in 1972, only 23.2% in 1998. U.S. nuclear -energy use rose from 0.6 quadrillion Btu per year in 1972 to 7.2 quadrillion Btu per year in 1998, a difference equivalent to 3.1 million barrels per day of oil; (*2) the nuclear share of U.S. energy supply went from 0.8 percent in 1973 to almost 8 percent in 1998. U.S. use of renewable energy sources, finally, grew from 4.5 quadrillion Btu per year in 1973 (two thirds of it hydro power, nearly all of the rest biomass) to 7.1 quadrillion Btu per year (51% hydro, 43% biomass, 4% geothermal, 1% solar, 0.5% wind), the growth over this interval being equivalent to 1.2 million barrels of oil per day in 1998; the renewable share in the U.S. energy mix was 6.1% at the beginning of this period and 7.5% at the end.

What can be said, then, about the potential for reducing U.S. oil-import dependence in the future?

First, by far the biggest immediate and short-term leverage - as well as a very sizable share of 'the leverage in the longer term - lies in increasing the efficiencies of oil use (which helps directly) and of energy use overall (which frees up non-oil sources of supply than can then, in principal, substitute for oil). Notwithstanding the impressive efficiency gains between 1972 and today, the technical potential for further improvements remains very large. Rates of improvement in energy efficiency have declined since 1985 because energy prices declined and the non-price policies in place to encourage efficiency in that period were insufficient to make up the difference. This could be changed. If a combination of market-based and other measures were put in place that made up half the distance between the 1985-1999 rate of reduction of energy intensity of the U.S. economy (1.2% per year) and the 1979-1985 rate of reduction (3.2% per year) - thus making the rate of improvement after 2000 a round 2.2% per year - and if the economy grew steadily after 2000 at 3% per year real, the additional energy savings from these efficiency improvements would amount to about I I quadrillion Btu in 2010 (equivalent to about 5.5 million barrels of oil per day) and about 43 quadrillion Btu in 2030 (equivalent to about 21 million barrels of oil per day).

The technical potential for efficiency improvements is nowhere more apparent than in the oil sector itself, where over 12 million barrels per day of petroleum products are used for transportation, 8 million barrels per day of that in the form of gasoline (used mostly in cars, light truck, and motorcycles) and 2 million barrels per day of it diesel fuel (used mostly in heavy trucks and buses). Average automotive fuel economy in the United States has been essentially constant since 199 1, at about 21 miles per gallon, the previous trend of improvement having been capped by the combination of low gasoline prices, the absence in recent year's of increases in the Corporate Average Fuel Economy (CAFE) standards, and the growing proportion, in the personal-vehicle mix, of sport utility vehicles and pick-up trucks for which the current CAFE standards are lower than for ordinary cars.

But perfectly comfortable and affordable hybrid cars already on the market get 60 to 70 miles per gallon; and fuel-cell powered cars that, with the help of the government-industry Partnership for a New Generation of Vehicles, could be on the market before 2010 should be able to get 80 to 100 miles per gallon, ultimately perhaps more. The arithmetic is simple: doubling the average fuel economy in a fleet of gasoline-burning vehicles the size of today's would save 4 million barrels of oil per day, more in the larger fleet that is likely to exist tomorrow. In the 1997 PCAST study I led on US energy research and development strategy, we estimated that PNGV research culminating in commercial production of advanced vehicles in 2010 could be saving 4 million, barrels per day in the United States by 2030. Research to improve the fuel efficiency of light and heavy trucks, also assumed to culminate in commercialization in 2010, was estimated to be able to save another 2 million barrels per day by 2030. (Of course, none of this will happen if the R&D is not done, or if incentives to commercialize the resulting innovations are absent; more about that below.)

On the supply side, the potential to abate the slide in domestic oil production seems quite limited by comparison. Under the "reference" scenario of the Energy Information Administration's *Annual Energy Outlook 2000*, which assumes a degree of continuing technological innovation in domestic oil production, domestic oil production declines by 0.6 million barrels per day between 1998 and 2005 and then remains flat at around 7.3 million barrels per day from 2005 until 2020. An alternative scenario in which the world oil price in 2020 reaches $28 per barrel (in 1998 dollars, compared to $22 per barrel in these constant dollars in the reference scenario) yields domestic production in 2020 only 0.8 million barrels per day higher than in the reference scenario, barely more than the 1998 level. (In the EIA scenarios, oil imports in 2020 in the reference case are 17.2 million barrels per day, and in the higher-oil-price case they are 15.4 million barrels per day.) The 1997 PCAST energy R&D study projected that application of the additional R&D it recommended on exploiting marginal domestic petroleum resources would yield only about an extra million barrels per day in 20 10, which would not increase further out through 2030.

Some are suggesting that important leverage on the domestic-oil-production side of the problem could be gained by opening the coastal shelf of the Arctic National Wildlife Refuge (ANWR) to oil development (from which, it appears, no contribution was assumed in any of the EIA scenarios). The numbers do not suggest that this is a high-leverage proposition, however. It is not certain that oil would be found in the ANWR. Estimates of how much might be recoverable, if it is found there, have ranged from 3 billion barrels (by the Congressional Office of Technology Assessment in 1989), to 3.6 billion barrels (by the Department of Interior in 1991), to 4-12 billion barrels (by the USGS in 1998). This means, in round numbers (and assuming oil would be found there in one of the indicated quantities), that could provide between 6 months and 2 years' current US oil supply, or I to 4 years' current imports, or 4 to 16 years' current imports from the Persian Gulf.

To anticipate an actual oil-production trajectory, one may note that, at the upper end of the range of estimates, the ANWR would be comparable to the Prudhoe Bay field; if that were so, a production trajectory similar to Prudhoe Bay's would presumably ensue - a couple of decades of production at 1.5-2 million barrels per day and a few decades thereafter at around I million barrels per day. The question that policy makers must answer is whether the possibility of a contribution of this magnitude justifies the modest but certain environmental damage of exploration - and the certainty of larger environmental damage from production and transport if oil is found. Given that a comparable contribution to oil-import reduction could be obtained by pushing only modestly harder for efficiency increases, and given that doing the job with efficiency instead would have large ancillary environmental benefits (such as reductions in emissions of air pollutants and greenhouse gases) rather than major environmental costs, my own view is that the right answer on ANWR is "no"

The supply-side options with the largest short-term and medium-term potential to directly displace oil in the U.S. energy mix are natural gas and biofuels. Natural gas could displace oil in a number of industrial applications, in home heating, and in motor vehicles (where engines have been modified to run on compressed natural gas, or on methanol made from natural gas, or where fuel cells running on hydrogen made from natural gas have replaced combustion engines). The 1997 PCAST energy R&D study discussed these possibilities but did not offer specific estimates of potential contributions over time.

The EIA Annual Energy Outlook 2000 scenarios for 2020 include contributions of natural gas as motor-vehicle fuel up to some 200,000 barrels per day. The potential is clearly larger, however. The source of the natural gas for these oil-displacing transport-fuel options could be displacement of gas from electricity generation by other non-oil options (about which more below) or extra domestic natural-gas production resulting from increased rates of 'technical innovation in gas exploration and recovery. (The difference in domestic natural-gas production in 2020 between the "high technological change" and "low technological change" EIA scenarios is 4 quadrillion Btu per year, the equivalent of 2 million barrels of oil per day.)

As for liquid fuels from biomass, the 1997 PCAST study estimated that an aggressive program to produce ethanol from cellulosic biomass could be displacing 2.5 million barrels per day of oil by 2030 and over 3 million barrels per day in 2035. The PCAST report also identified other biofuels options for this time period without attempting to estimate their potential quantitatively. This indicates that the 2.5-3 million barrel per day range by 2030-35 is not an upper limit. The EIA scenarios, by contrast, only show about 125,000 barrels per day of motor-fuel displacement by ethanol in 2020, but that study did not give much attention to possibilities for rapidly expanding non--electric renewable-energy technologies. I believe the PCAST assessment gives a more meaningful indicator of the direct oil-displacement potential of biomass fuels.

The Administration's initiative on "Promoting Bio-based Products and Technologies", announced last August, posed a target of tripling use of energy and products from biomass in the United States by 2010. (This would include the use of biomass for electricity generation and cogeneration, about which more below, as well as production of high-value chemicals.) Inasmuch as biomass energy use in this country in 1998 was about 3 quadrillion Btu per year, the stated goal implies an addition of 6 quadrillion Btu per year by 2010, equivalent in energy content to 3 million barrels per day of oil.

Production of liquid hydrocarbon fuels from coal is technically feasible using a variety of relatively well developed approaches, but it is not economically competitive with oil at recent or current oil prices, nor is it currently competitive with production of liquid fuels from natural gas. In addition, production of liquid fuels from coal using existing technology results in carbon dioxide emissions to the atmosphere about twice as large, per barrel, as for petroleum, which would be a major drawback in light of the desirability of minimizing climate-change risks. As oil and natural gas become more expensive over time, advanced coal-to-liquids technologies that can capture and sequester carbon dioxide rather than releasing it to the atmosphere may eventually become attractive. The 1997 PCAST study concluded that "indirect" liquefaction of coal (which entails gasifying it first and then making liquid fuels from the gas) is far more promising in its combination of economic and environmental characteristics than "direct" liquefaction; we recommended phasing out DOE's research on direct liquefaction and shifting the funds into the gasification-based "Vision 21 " program for advanced coal technology and into R&D on carbon sequestration and other forms of emissions reduction.

There is some potential for reducing U.S. oil consumption by replacing oil-fired electricity generation with other fuels, but it is quite limited. In 1998, oil generated only 3.6% of U.S. electricity, and doing so accounted for only about 3% of U.S. oil consumption (about 600,000 barrels per day). Most of the potential that this represents is captured in the EIA reference scenario, where a 3-fold drop between 1998 and 2020 in oil use for electricity generation reduces oil use by 400,000 barrels per day. Much of the rest of the leverage of the electricity sector against oil consumption is indirect, through the potential of alternative electricity options to displace natural gas from electricity generation, which as noted above could in turn displace oil in the industrial, residential, and transport sectors. Electricity can also displace oil through the electrification of some of the end-uses that oilserves, such as replacing residential oil-fired heaters with electric heat pumps and shifting commuters out of their cars and into electricity-powered public transit systems. The latter has so far proven very difficult to achieve on a large scale, however, and the former represents only a modest market nationally: home heating with oil uses only about 1. 1

quadrillion Btu per year, corresponding to an average of some 500,000 barrels per day if pro-rated over the year.

Total U.S. electricity generation in 1998 was 3620 billion kilowatt-hours, of which 1872 billion kWh came from coal, 674 billion kWh from nuclear energy, 532 billion kWh from natural gas, 129 billion kWh from oil, 324 billion kWh from hydropower, 55 billion kWh from biomass, 14 billion kWh from geothermal, 3.5 billion kWh from wind, and 0.9 billion kWh 6om solar energy. In the EIA's reference scenario for 2020, coal-fired electricity generation increases to about 2300 billion kWh, gas-fired generation increases to nearly 1300 billion kWh, nuclear energy declines to about 425 billion kWh (because of retirements of some of the existing nuclear power plants in the absence of replacement by new ones), and renewable-based electricity generation in aggregate stays roughly constant.

From an environmental standpoint and quite possibly also from an economic one, the most attractive candidates to displace some of the growth of gas-fired generation envisioned in the EIA scenario (and thereby make gas available to displace oil in other sectors) are the non-hydro renewables. A very conservative estimate of their potential for doing so out to 2020 is provided by the EIA "high renewables" scenario, which in 2020 obtains 112 billion kWh from biomass, 62 billion kWh from wind, 40 billion kWh from geothermal, 2.7 billion kWh from solar. The additional non-hydro renewable generation in this scenario, compared to the 1998 figure, totals 140 billion kWh - equivalent to 700,000 barrels per day of oil.

This EIA estimate of renewable-electric potential is conservative because the EIA study did not consider the possibility of world oil-price increases above 28 1998 dollars per barrel or the possibility of major policy changes that would have the effect of sharply increasing the incentives for expanding the use of non-fossil-fuel options. The 1997 PCAST study made some estimates of what might be achievable from renewable-electric options under prices or policies that encouraged these options very strongly, and the resulting figures were far higher than those in the EIA scenario: they included as much as I 100 billion kWh by 2025 from wind systems with storage technologies, similar quantities by 2035 from photovoltaic and solar-thermal-electric systems with storage, 800 TWh by 2035 from biopower, and 1500 TWh by 2050 from hot-dry-rock geothermal. These are described as possibilities, not predictions, but the figures are indicative of very large potential: 1000 billion kWh per year is the equivalent of 5 million barrels of oil per day.

Because there are no new nuclear power plants on order in the United States - and not likely to be 8 long as gas-fired electricity generation remains much cheaper than nuclear generation -- the range of nuclear contributions in 2020 in the EIA, scenarios depends only on the rate of nuclear-plant retirements versus-license extensions for additional years of operation. The difference between the EIA's "high nuclear',' and "low nuclear" variations in these respects amounts to 200 billion kWh in 2020, equivalent to I million barrels of oil per day. The 1997 PCAST study recommended a modest increase, in Federal nuclear-energy R&D in order to clarify safety issues associated with license extension, and it recommended a somewhat larger and longer-term Nuclear Energy Research Initiative focused on clarifying the prospects for improvements in the cost, safety, waste-management, and proliferation-resistance characteristics that will determine whether deploying a new generation of nuclear reactors in the United States in the longer term becomes a real option. PCAST also recommended an increase in the funding for R&D on fusion energy, which although it remains far from commercialization today could conceivably make a large contribution to electricity generation in the second half of the 2 1st century.

The overall technical potential to reduce U.S. oil dependence through the use of a wide range of currently available and still to be fully developed alternative technologies is clearly very large. The key to the use of the currently available options is incentives, about which more below. The keys to achieving the potential of the emerging options are, first, research, development, and demonstration; and, second, incentives to help bring about the commercialization and widespread deployment of the innovations that result from research, development, and demonstration.

Concerning energy research and development, the 1997 PCAST study argued that such R&D is valuable for a range of reasons. Not only can innovation in- energy technology help reduce costly and dangerous over-dependence on foreign oil, PCAST said, but it can reduce consumer costs for energy supplies and services below what they would otherwise be, increase the productivity of U.S. manufacturing, improve

U.S. competitiveness in the multi-hundred-billion-dollar-per-year world market for energy technologies, improve air and water quality, improve the safety and proliferation resistance of nuclear energy operations around the world, help position this country and the world to cost-effectively reduce greenhouse-gas emissions to whatever degree our societies ultimately deem necessary, and enhance the prospects for environmentally sustainable and politically stabilizing economic development in many of the world's potential trouble spots.

Many of these benefits fall under the heading of "public goods", meaning that the private sector is not likely to invest as much to attain them as the public's, interest warrants. That is one of the principle reasons why, even though the private sector does and will continue to do a great deal of valuable energy R&D, there remains a powerful rationale for government support for and participation in such R&D, as well. I should perhaps emphasize at this point that there was strong industry representation on the PCAST energy R&D panel -- and balance across the fossil-fuel, nuclear, renewables, and end-use-efficiency sectors. I also want to emphasize that many of the recommendations involved the expansion of public-private partnerships in energy research, development, and demonstration, helping to ensure an appropriate combination of market relevance and public benefits in the results.

Notwithstanding the indicated benefits of strong government participation in energy research, development, and demonstration, the PCAST panel found that Federal funding for applied energy-technology R&D had declined drastically in the preceding two decades. Just prior to the first oil-price shock in 1973, this spending had totaled about $1.3 billion per year (converted to constant 1997 dollars), more than 80 percent of it for nuclear fission and fusion and most of the rest in fossil-fuel technologies. Between 1974 and 1978, the total shot up to over 6 billion 1997 dollars, in pursuit of "Project Independence" - independence, that is, from foreign oil. This large expansion in Federal energy R&D was accompanied by a great diversification, with large increments for renewables and -efficiency in addition to expansion of the nuclear and fossil-fuel efforts. But after 1978, these expenditures went into a long decline, interrupted briefly and modestly in 1987-92 by an expansion of public-private partnerships in clean-coal R&D; by FYI 997, Federal investments in applied energy-technology R&D were back to the 1973 level - $1.3 billion per year in constant 1997 dollars. (The diversity of the FY1997 program was much greater than that of FY1973, however, being quite evenly split among nuclear energy, fossil fuels, renewables, and efficiency; within the nuclear part, fission had almost disappeared, with fusion dominant. As a fraction of real GDP of course, the 1997 energy technology R&D funding was only about half that of 1973.)

Although some of the post-1978 reductions represented cancellations of oversized development projects that deserved this fate, the PCAST panel concluded that the Federal energy -technology R&D programs that remained in 1997 were "not commensurate in scope and scale with the energy challenges and opportunities that the twenty-first century will present", taking into account "the contributions to energy R&D that can reasonably be expected to be made by the private sector under market conditions similar to today's". Accordingly, the panel recommended modifications to DOE's applied energy-technology (fossil, nuclear, renewable, efficiency) R&D programs that would increase funding in these categories from their FY1997 and FY1998 level of $1.3 billion per year to $1.8 billion in FY 1999 and $2.4 billion in FY 2003. The principal recommended increases were (in descending order) in efficiency, renewable, and nuclear (fusion and fission) technologies; recommended initiatives in the fossil category were largely offset by recommended phase-outs. The proposed R&D portfolio addressed the full range of economic, environmental, and national-security challenges related to energy, in their shorter-term and longer -term dimensions. Also recommended were a number of improvements in DOE's management of its R&D efforts. Notwithstanding the diversity of the panel and the complexity of the issue, all of these recommendations were unanimous; there were no dissenting views.

The administration embodied a considerable fraction of this advice in its FYI 999 budget request (which contained a total increment about two-thirds of what PCAST recommended for that year) and the Congress appropriated a considerable fraction of that (about 60 percent of the increment requested by the administration). The net result was an increment about 40 percent as large as PCAST recommended for FY1999. The overall PCAST recommendations for FY1999 through FY2003 and their fate in administration requests and Congressional appropriations so far are summarized in the following table. As is apparent there, the requests and the appropriations are growing, but not nearly as rapidly as PCAST recommended. What has been achieved is much better than nothing; but it is not enough.

As a follow-up to a recommendation in the 1997 study that more attention should be devoted to the opportunities for strengthening international cooperation on energy innovation, PCAST conducted in 1998-99, at the President's request, an additional study (which I also chaired) focused on the rationales for and ingredients of an appropriate Federal role in supporting such cooperation. The resulting 1999 report, "Powerful Partnerships", noted that many characteristics of the global energy situation that affect U.S. interests will not be adequately addressed if responses are confined to the United States, or to the industrialized nations as a group. The oil-import problem is one compelling example of this, insofar as the pressures on the world oil market - and the disruptive potential residing in the concentration of the world's oil resources in the Persian Gulf -- depend on the extent to which many other countries besides the United States are relying on imported oil. The solution therefore depends on the pace at which oil-import-displacing energy options are deployed in other countries, not just in the United States.

The panel found that the world oil problem is far from the only reason for international cooperation on energy-technology innovation, however. This case was summarized in the letter of transmittal as follows:

How the global energy system evolves in the decades ahead will determine the extent of world dependence on imported oil and the potential for conflict over access to it; the performance of nuclear energy systems on whose safety and proliferation resistance the whole world depends; the pace of global climate change induced by greenhouse-gas emissions from fossil-fuel combustion; and the prospects for environmentally sustainable economic development that will build markets for US. products and reduce the role of economic deprivation as a cause of conflict. US. participation in international energy-technology cooperation, informs and degrees beyond what can or will be undertaken by the private sector alone, is also likely to be crucial in gaining and maintaining access for US. firms to many of the fastest-growing segments of the multi-hundred-billion-dollar-per-year global energy-technology market.

The panel found further (this from the Executive Summary) that

existing Federal activities in support of international cooperation on energy innovation -.carried out by DOE, USAID, and a variety of other agencies and spending altogether about $250 million per year - are generally well focused and effective. But they are not commensurate in scope and scale with the challenges and opportunities that the international energy arena presents, and they suffer from the lack of an over-arching strategic vision and corresponding coordination to link the activities within and across the agencies into a coherent whole. A particularly conspicuous gap in the government's energy- cooperation activities exists in the demonstration and cost-buy-down stages of the innovation process (between R&D, where DOE's efforts are mainly focused, and deployment, where the activities of the trade-promotion and development agencies are mainly focused). The dearth of activities in this category is substantially slowing the pace at which advanced energy technologies reach commercial viability.

It recommended

substantially strengthening these Federal efforts -- expanding their coverage, increasing their funding, improving the processes for their evaluation, and providing for them an over-arching strategic vision and a mechanism for coordinating its implementation. We propose specific initiatives for strengthening the foundations of energy-technology innovation and international cooperation relating to it (including capacity building, energy-sector reform, and mechanisms for demonstration, cost-buy-down, and financing of advanced technologies); for increased cooperation on research, development, demonstration, and deployment (RD3) of technologies governing the efficiency of energy use in buildings, energy-intensive industries, and small vehicles and buses, as well as of cogeneration of heat and power; and for increased cooperation on RD3 of fossil-fuels -decarbonization and carbon-sequestration technologies, biomass-energy and other renewable- energy technologies, and nuclear fission and fusion. Most importantly -for without this none of the other initiatives we propose are likely to achieve their potential - we recommend creation of a new Interagency Working Group on Strategic Energy Cooperation, under the auspices of the National Science and Technology Council, to provide a strategic vision of and coordination for the government's efforts in international cooperation on energy-technology innovation. The government's contribution to this expansion of international energy cooperation activities would be provided by a new Strategic Energy Cooperation Fund amounting to $250 million for FY2001 and increasing to $500 million in FY2005, the proposed allocation of which to the relevant agencies in the President's budget request would be determined with the help of the Interagency Working Group.

In a decision memorandum last September responding to the report, President Clinton directed that the indicated interagency working group be formed and that the relevant agencies consider the PCAST panel's funding recommendations in preparing their FY2001 budget requests. All this was done. The budget request ultimately submitted by the administration to the Congress contains $ 100 million in FY2001 for initiatives arising from the new PCAST recommendations. I very much hope the Congress will treat these initiatives favorably, because I believe that they - along with the national energy R&D initiatives recommended in the 1997 PCAST study -- represent indispensable ingredients of the technology component of an appropriate strategy for addressing the oil-import challenge as well as many other ingredients of the energy/economy/environment problem.

Another crucial ingredient of such a strategy is the array of price and non-price incentives and other policies that will shape the pace at which the best available technologies for reducing oil imports get deployed (as well as affecting the pace of private-sector research to improve such technologies) ... but that is a matter for another day. I thank you for the opportunity to put these views before the Committee.

(*1) There are many minor variations in the way such percentages are computed and reported. These figures and most others in this testimony are from the U.S. Energy Information Administration's Annual Energy Review, 1998, published in July 1999, augmented by the February 2000 edition of the EIA's Monthly Energy Report.

(*2) Oil use for electricity generation, which is the main application where nuclear energy currently substitutes directly for oil, was only 1.5 million barrels per day in 1973 and by 1998 had fallen to 0.5 million barrels per day. The implications of this for the future leverage of nuclear-energy expansion against oil-dependence are discussed below.

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