NEGATIVE POPULATION GROWTH

THE NPG FORUM

ENERGY AND POPULATION:
Transitional Issues and Eventual Limits

by Paul J. Werbos

This is the ninth in a series of NPG FORUM papers exploring the idea of optimum population—what would be a desirable population size for the United States? Without any consensus even as to whether the population should be larger or smaller, the country presently creates its demographic future by inadvertence as it makes decisions on other issues that influence population change.

The approach we have adopted is the "foresight" process. We have asked specialists in various fields to examine the connection between alternative population futures and the national or social objectives in their fields of interest. In this issue of the FORUM, Dr. Werbos examines U.S. energy requirements and the U.S. population size that would be compatible with a plentiful supply of environmentally benign energy.

The question does not lend itself to formal proof. There are too many variables and value judgements. Yet it must be addressed.

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This paper was drafted before the Iraqi invasion of Kuwait. Some of the developments presented as contingencies have now become realities. Any person interested in understanding the long term implications of that invasion and the subsequent rise in oil prices would do well to read this essay.

—Lindsey Grant, Editor

Overview

The editors of this series have asked me to address what appears to be a straightforward set of questions: what U.S. population size is compatible with the environmental consequences of energy use? What levels of population would lead to maximum efficiency in the energy sector, as a guesstimate, in long-term equilibrium?

Many energy analysts tend to ignore the population question, or to treat population as a minor background variable in forecasting twenty years into the future. A few analysts, following the first report to the Club of Rome, decry all forms of economic and population growth. Both sides—the pessimists and the defenders of the status quo—have built elaborate models and theories to defend their viewpoints, often based on questionable hidden assumptions. After years of working through this maze of theories and building a few models myself, I would make the following personal judgements[1] about energy and population:

(1) The present mix of fuels and energy technologies is not sustainable in the long-term, even if population were dramatically reduced. In the long term, fossil fuels will run out. Even now, our present ways of using energy have led to unhealthy levels of ozone in almost every American city, to toxic pollution leaking into ground water and into natural bodies of water. In the next decade or two, oil imports may return to being a crisis-level problem, as demand increases and domestic supply decreases, almost inevitably. Sooner or later, we must also deal with the problem of greenhouse warming, which is associated with all realistic uses of fossil fuels.

To meet all the present energy demands, worldwide, plus economic growth, with conventional nuclear power, would imply an *accumulating* problem with nuclear waste, nuclear proliferation, nuclear material available for terrorists, and nuclear safety orders of magnitude larger than what we face today.

(2) Once a complete transition to sustainable technologies is achieved, we could probably sustain a wide range of possible populations at a reasonable level of efficiency. From an efficiency viewpoint, populations between 50 to 100% of the present population would probably be ideal, though environmental quality would probably be better at the lower end of the range. Populations as low as 25 million or so would probably be a problem, because it would be difficult to sustain a complex mix of technologies (even soft technologies) on such a small engineering base; however, we probably could not sustain a population much greater than that if we insisted on using only less expensive, less risky soft technologies. With a high degree of optimism about the soft technologies, and allowances for peak load electricity supplied by solar power, one might hope to sustain a population as large as 60 million or so. For larger populations, we would probably have to rely mostly on direct solar technologies, including a certain mix of technologies as yet unproven. Populations much larger than the present would begin to present problems, because solar energy would become more expensive (due to higher land prices) and also because the concentration of water pollution tends to increase in proportion to population. If our income per capita were as low as that of China, we could support a similar population, but in an economy as rich as ours the pollution and land supply problems would become difficult.

(3) Regardless of long-term sustainability, the growth of population and the composition of this growth in the next two to three decades is possibly the most serious problem reducing our chance of a successful transition to sustainable technology. At first glance, the connection may not be obvious, but it is really quite strong. Sustainable technologies will take a long time to bring onto the mass market, and the transition will cost billions upon billions of dollars. An important part of the cost will involve research and development which is highly profitable in the long-term; even so, finding the money in the next five years will clearly be a problem—and the next twenty years may not be radically different from the next five.

In these circumstances, the nation will be well advised to do whatever it can to slow the present rate of population growth and the increased energy demand posed by a larger population. Perhaps more important, it needs to change its investment habits to accumulate the capital to make the transition away from petroleum. The biggest obstacle to finding the money—either in the public or private sector—is the general shortage of capital associated with a low national savings rate and the federal budget deficit. We need a skilled and productive labor force. Neither our immigration policies nor our national social policies are focused on this goal. We admit immigrants based on kinship rather than skills. We face rising teenage pregnancy and continuing differential pregnancy—with the poorest who can least afford to raise them having the most children. We wrestle with the costs and results of these problems, rather than trying to avoid them. The costs are very high, and they divert resources from the challenges ahead. A national policy preparing us to cope with those challenges would probably result in immigration and fertility levels corresponding roughly to the "hard path" described by Leon Bouvier elsewhere in this series, and an immediate slowing of population growth.

Finally, it is not obvious that the United States will be able to make the transition to sustainable technologies in time to prevent severe, debilitating rises in energy prices and environmental problems worldwide. Rising energy prices and shifts in the composition of the labor force can slow down economic growth, making it ever more difficult to make such a huge transition, if we wait too long. The solutions and the problems will both take decades to develop, and no one knows which will happen first. If demographic problems over the next few decades result in too much of a delay here, the consequences for our civilization might well be permanent.

The remainder of this paper will elaborate on some of these points. First it will discuss the near-term problem of dependency on oil, and the difficulty of achieving a transportation system which frees us from that dependency. Then it will discuss the longer-term issues of how we fuel this transportation sector and other sectors of the economy.

Oil: Its Importance, Its Future and How to Escape

Oil and gas currently account for 66% of the primary energy consumed in the U.S.[2] Oil and gas are both in highly finite supply, and there will be major difficulties in replacing them. Oil, in particular, tends to be used in applications where it is difficult to substitute other fuels. Unless there is gross mismanagement of the electric utility sector, shortages and high prices for oil are likely to be the next major "crisis" in the energy sector, just as they were in the 1970's.

The last great oil crises came in 1974 and 1979, when oil prices rose 119% and 42%, respectively[2]. These oil crises led immediately to slowdowns in economic activity. From 1973 to 1975, GNP was reduced by 10.6% compared to the previous growth path (1961 to 1973); this works out to a loss of $285 billion in 1982 dollars, just in 1975. From 1978 to 1980, the loss was more like 6%. Those who remember living during those days of gas lines and uncertainty may remember how this understates the actual pain involved. (For example, time lost in gas lines does not show up in the GNP.) Also, it does not really account for the loss to our balance of payments, which leads to a loss in our ownership of our own economy; if we produce a lot of goods but do not own what we produce, our own well-being may suffer.

Was this loss of GNP in 1974 and 1979 really due to the oil price rises? Some economic models predict that price rises of this sort should have little short-term impact; however, most of those models have a "potential GNP" equation which does not depend on energy, or assumes that it is easy to replace energy with capital or labor. In effect, they *assume* that we can easily produce goods without using energy (even in cases where energy is represented in great detail in *other* equations of the model). Naturally, they do not predict big impacts in the future either. One famous modeler, whose model could not explain the full impact of the 1974 price rises, came up with a very ingenious excuse, which he used in selling his model during the Reagan administration: he argued that it was the *government's* fault that the GNP fell so much, due to mismanagement by the Nixon-Ford Administration; however, his model assumed a very high price elasticity (i.e. easy replacement of energy), which is enough to explain the failure of its forecasts. However, the Wharton Annual Energy Model of the 1970's did contain a detailed account of how energy influences the economy, in the short-term, through a detailed representation of production; that model *was* able to explain[3] the economic downturn in 1973-75, and would also predict larger short-term effects in case of future price rises.

Does this loss of $285 billion in 1975 represent the full cost of the price rise of 1974? Many analysts simply calculate this kind of short-term loss, and assume that the economy bounced back thereafter to its previous growth path. However, if the previous growth path depended on tangible things like investment, this becomes a questionable assumption. The well-known economist Dale Jorgenson has shown very convincingly that one would expect a *long-term* effect, shifting both the level and the rate of growth of GNP. In fact, the year 1974 marks a sudden and very disturbing shift in the U.S. economy, from a sustained growth in the 4% range—based on large growth in productivity—to sustained growth in the 0-1% range. The growing percentage of women working for wages has helped to keep up the growth in average monetary income over the past 15 years, along with tax cuts, but real wages *per person working* have not grown in this period. Real wages are probably a better measure of economic well-being than income per capita.

The evidence cited here suggests that the drop in productivity growth after 1974 might be due to higher energy prices; however, other explanations are possible. For example, one might argue that short-term efforts to keep up high standards of consumption, despite the rise of energy prices, led to short-sighted actions which lowered productivity growth—such as cuts in research and development. Some economists have argued that changes in the labor force—related to the population issues alluded to in the overview—were the major culprit. If *any* of these arguments is correct, then the problems cited in the overview would be the main culprit for this chronic loss in economic growth since 1974. Our hopes of returning to sustainable economic growth, and restoring that high spirit and morale which led us to the moon, may depend on solving our energy and population problems. Those who believe that lower oil prices have already begun to bring back some of the old high spirits in the last two to three years should be concerned about the danger of going *back* into malaise, if oil prices go back up again.

What are the dangers of new oil crises, leading to effects as large or larger than those of the 1970s? The basic situation which allowed an oil crisis in 1974 was the growth in U.S. dependency on imported oil. By 1974, U.S. oil imports had grown to 35% of our oil consumption, and 20% of the total came from OPEC[2]. *Those* are the numbers which made us vulnerable to unexpected events in the Middle East. By 1979, the situation was worse, with a 43% import dependency and a 30% OPEC dependency. In fact, the *steady* rise in oil prices from 1973 to 1981 was undoubtedly a factor in the lower economic growth in that period.

By the late 1970's, it seemed clear to many people that low or stable oil prices were a thing of the past. As a result, there were massive changes in energy use, including one-time improvements in efficiency, and conversion from oil to other fuels in markets where conversion was relatively easy. This, in turn, led to reduced oil demand, and downwards pressure on prices. By 1986, there was talk of an oil glut. However, even *before* prices bottomed out in 1986, oil imports began to rise again, as certain inexorable forces began to reassert themselves. From 1986 to January 1990, oil prices rose back to $20 per barrel, about half again as large as the 1986 price[2]. But from 1986 to 1989, our dependency on oil imports rose back from 33% to 41% (and is still rising); our dependency on OPEC rose from 17% to 24%, despite the rise in oil prices. We are now more vulnerable than we were in 1974, and we are moving rapidly back to the 1979 level. From 1988 to 2010, EIA now forecasts that U.S. oil imports will double[4], based on a relatively conservative analysis of these trends. All of this implies a relatively serious threat to the U.S. economy, growing steadily without an end in sight.

Looking beneath the surface, the dangers are even greater than the import numbers would suggest. For one thing, the situation in the MidEast appears more intractable than it did in 1974, particularly in the light of nuclear and chemical weapons proliferation. For another thing, there is less slack in our use of energy than there was in 1974. The easy things have already been done. From 1974 to 1989, the use of oil in the residential/commercial sector dropped by 30%, and the electric utility use of oil dropped by 50%. Most people who could convert easily to natural gas have done so.[5] (Many areas still lack sufficient gas pipeline capacity, however.) As a result, the transportation sector grew from 53% of oil use to 63%. The remaining oil use in the U.S. is overwhelmingly concentrated in vehicle use in industry (such as tractors and bulldozers), and in petrochemical feedstock use.[6]

In brief: further reductions in oil use—either in a crisis or before—will mainly have to come from cutbacks in motor vehicles, or cutbacks in our use of bulk plastics and petrochemicals.

How hard would it be to make such cutbacks in a crisis, if we did not have time to change our capital stock? In a future crisis, our main opportunity to cut back on oil use would be through reductions in driving. From historical data, it seems overwhelmingly clear[7] that a 1.0% increase in the real price of gasoline reduces driving by only 0.2%; in economists' jargon this is a price elasticity of -.2/1.0 or -20%. To cut back driving by 10% without a direct reduction in personal income would thus require something like a 60% increase in prices. The loss of all U.S. oil imports from OPEC—which are far more than 10%—would therefore seem to imply a bigger impact than we observed in 1974 or 1979.

What would happen if we allowed for the possibility of conservation, so that cars get more efficient, but they still use gasoline in internal combustion engines? In actuality, the EIA forecasts have *already assumed* a very high level of conservation, rising to 35 miles per gallon for the *average* new car.[5] Higher mpg is possible, of course, in small or slower cars, but the research embedded in these assumptions was based on very extensive studies of what the public is or is not willing to buy under different price regimes—something which the private sector has been very sincere about wanting to know.[7] Phil Patterson, of the Conservation Office of DOE, published a critical review of the EIA efficiency assumptions in a recent

World Energy Conference in Paris. Patterson argued very persuasively that the EIA assumptions were on the optimistic side. Patterson's review was especially persuasive, because it drew heavily on work by engineering research groups who had worked with people like Amory Lovins in the past, and comes from an office which seriously tries to champion the cause of conservation. In summary, continued conservation is expected to have an important impact on oil use, but it is not enough by itself to prevent a worsening situation on imports.

There are laws in thermodynamics, discovered by Carnot, which limit the ultimate efficiency of internal combustion engines and other heat engines. Back when engines were highly inefficient, there was substantial waste and slack which allowed a rapid improvement in mpg until 1982. Many econometric models show more potential for conservation, because they are based in large part on data from that period, and do not account for the diminishing returns which are obvious in the engineering. (Also, they usually focus on "new car" mpg, without accounting for the shift of many car buyers towards pickup trucks and vans.) Nowadays, engines are pushing the limits of what is physically possible with this class of engine; already the complexity of new systems has begun to create problems involving cost and maintenance. Serious improvements in aerodynamics and lighter materials are certainly possible, but are already assumed in the forecasts. To do a whole lot *better* than the existing forecasts—and to avoid massive disruptions in the case of import cutbacks—one would have to go beyond the use of gasoline in heat engines.

Back in the era of Jimmy Carter, synthetic fuels were supposed to solve these problems. However, early cost estimates for synthetic fuels—like estimates for nuclear power and many other complex new technologies—were off by a factor of two or three. Ed Merrow of the RAND Corporation performed a more in-depth analysis of cost escalation, and predicted costs more like $3/gallon (in 1980 dollars) for gasoline based on synfuels technologies. This did not include the environmental costs, which would have been large as well. If the United States consumes 100 billion gallons of gasoline per year, now priced at under $1/gallon (in 1980 dollars), then the cost of switching entirely to synfuels would have been over $200 billion per year—not the kind of thing one likes to do a decade early for the sake of insurance.

The current President has chosen, for excellent reasons, to focus on methanol as the immediate way out of this dilemma. Economists from Ford have argued that one gets more miles per ton of coal if one converts the coal to methanol, and uses it as methanol, rather than making synthetic gasoline.[8] Furthermore, the use of methanol opens the door to a whole variety of other fuel supplies (such as wood alcohol), and makes it far easier (as I will discuss) to change over to fuels like hydrogen in the more distant future.

If we assume 60 cents per gallon to produce methanol using established technologies,[9] and 30 cents per gallon for distribution, and account for the lower heat content of methanol, we arrive at a price of $1.80 per gallon equivalent, in 1989 dollars and in conventional automobiles. This is far less than what synfuels would cost. Unfortunately, it is still not as cheap as gasoline, and it still requires an expensive transition. Also, it only helps a little bit in reducing those emissions which cause ozone buildup (about 20%, my judgement—less than the 50% claimed by some authoritative advocates but more than the 0% claimed by critics). Ozone buildup is now a major health hazard in most American cities. Dual-fueled methanol-gasoline vehicles would have only half the driving range using methanol that they would with gasoline. (Driving range would be a serious problem with other alternate fuels as well, except for ethanol.) In 1989, Congress rejected an Administration version of the Clean Air Bill which would have mandated an initial effort to begin deploying this technology.

Finally, there are ways to move vehicles which are *not* covered by the Carnot limitations. Los Alamos National Laboratories[10] have made substantial breakthroughs in the development of methanol-powered fuel cells for transportation, breakthroughs which solve a wide variety of earlier problems. Such vehicles are expected to be twice as efficient as cars based on heat engines, *if* we use low-temperature technologies like the LANL technology (or others discussed by the National Hydrogen Association). These technologies now require the use of methanol or hydrogen as fuels. (Natural gas *might* become possible someday, with further research.) Ozone-related emissions are reduced by a factor of 10 or 20, conservatively. In this technology, a fuel cell provides electricity to an electric motor; therefore, if breakthroughs in battery technology should occur, the widespread use of the fuel-cell technology would make a further transition much easier.

Money has gone into this technology from both DOE and the private sector, and the most recent (unpublished) results are extremely promising. However, we are rapidly approaching a point where large investments will be required from the private sector, and it is uncertain whether the incentives now available are large enough. The House of Representatives recently added an amendment to the Clean Air Act of 1990 mandating an advanced vehicle program in Southern California, which might conceivably provide the required incentives. The bill is not yet law, there are special interests working very hard against it, and it is in any case just one step. There is room for much stronger incentives giving more positive (and profitable) encouragement to the automobile manufacturers. The most optimistic among us are hoping for thousands of fuel-cell vehicles per year by the year 2000, under a sustained push beyond what present circumstances point towards. Sober forecasters are expecting something more like 2010 to 2030—and many years more to achieve full penetration of the existing automotive fleet. Between the methanol suppliers and the auto manufacturers, the required investments will undoubtedly add up to hundreds of billions of dollars by the time we are through.

In summary, as stated in the overview, the solutions to oil dependency will take a long time and a lot of money, and may or may not actually happen (given our present political and budgetary climate). If we are lucky, they may come online before oil prices ratchet way up again, but no one knows which will happen first—the crisis or the cure. Anything which improves the budgetary climate could make a big difference here, and an early cessation of growth in the entitlements population would certainly help.

Transition to Sustainable Energy Supplies

Billions of dollars and decades of work will be required just to complete the transition away from oil, as described above. This transition away from oil is justifiably our most immediate priority in the energy sector, because of the need to minimize the threat of a big new oil crisis and to eliminate unhealthy levels of ozone in American cities. However, this still does not solve the problem of where to get the methanol in the long-term, and it does not solve the problem of sustainability across all sectors of the economy. Additional, expensive transitions will be required to solve these longer-term problems.

Traditionally, there are four "sources" of energy which could meet our long-term needs—conservation, renewables, nuclear and coal.

The Soft Path

Advocates of the "soft" energy path argue that we might create a sustainable energy system by combining conservation along with reliance on "soft" renewables such as biomass, solar water heaters, wind, hydro, and geothermal energy. Some conservatives have strongly endorsed this idea, and argued that this kind of transition will ocur easily and naturally, simply by relying on free markets and eliminating government interference (such as R&D on conservation and renewables).

As I will discuss later, there *are* some renewable technologies—like advanced solar cells—which *could* produce a very large amont of energy; however, the "soft" renewables are usually not defined to include these. In the past, when EIA published very long-term forecasts and documentation explaining those forecasts, the projections of supply from renewables were mainly based on carefully worked out estimates of the *upper limit* of potential supply. Hydroelectric supply is limited by the energy in our rivers; wind supply is limited by our supply of exploitable wind sources; etc. (EIA now predicts[4] that renewable energy will *lose* market share from 1990 to 2010, because of a combination of limited potential and economic forces.) By and large, the *total* potential from these sources is something like one-tenth of present U.S. energy consumption.

Advocates for specific soft technologies often argue for somewhat greater potential. For example, one report on biomass from OTA[11] began with an executive summary stating that wood alcohol might contribute as much as 10 quadrillion Btu (quads) of additional energy to our economy—by itself about 12% of what we use. But later volumes of that report warned that this assumed the widespread use of fast-growing evergreen monocultures, so as to double production, and an avoidance of soil conservation rules which USDA has laid down for croplands (rules which many believe are still inadequate to prevent soil loss). A more objective estimate of the sustainable potential would be less than half of that 10 quads.

Most of these upper bounds are based on physical constants—like flows of wind and water—which are independent of population. However, if population were reduced substantially, there would be a major increase in the potential supply of biomass energy, because there would be less competition from the food industry and other users of biomass. It is hard to guess how large this increase would be, in the absence of truly comprehensive studies. For example, if *all* the corn and wheat in the United States were converted to alcohol fuels (based on 2.6 gallons per bushel[12]), and if the U.S. crop were reduced in half to achieve sustainability (as per the Pimentels' essay in this series), this would yield 10 billion gallons per year—only 1.5 quads of gross energy, and only 0.8 quads net. On the other hand, OTA[11] has estimated that an additional 5 quads might be available from grasses and the like (*with* a smaller population), and one might hope to achieve greater net efficiency by developing new conversion technologies and the like. Personally, I incline towards conservatism here, but the uncertainties are large; I can imagine the possibility of a case for *doubling* the potential from soft technologies, if population were cut very sharply. This would still only amount to about of 20% of present U.S. energy consumption, which (together with a low-risk scenario for solar energy) explains the 60 million population figure in the overview. Again, I would not be surprised if a smaller figure showed up after more extensive analysis.

Serious advocates of the soft path have generally recognized these limits of soft energy supply, and have argued that conservation can bridge the gap. But 80% of the end-use fossil fuel used in the U.S. lies in two sectors—transportation and industry.[5] The preceding section described how conservation—important though it is—is far from enough to create a sustainable economy. Fuel-cell cars *would* allow a factor of two reduction in energy intensity, compared with the alternatives, but only at a price: the conversion losses in *making* methanol lead to only a marginal net improvement in efficiency.

The industrial sector is already going through a similar transition away from fossil fuel towards efficient electric technologies, without government intervention (aside from R&D). These technologies are relatively benign, environmentally, and they enhance industrial productivity; however, if one accounts for conversion losses in *generating* the electricity, they often lead to *greater* energy intensity in production. The energy used per *dollar* of product may decline, because the *quality* and *value* of products goes up (e.g., more effective drugs); however, this greater quality also leads to a greater total value of product (a *qualitative* growth in GNP), and the net effect on energy use is often positive.

Some economists have argued that higher energy prices should increase conservation in industry beyond the present trends; however, a recent comparison of the best in-depth models of industrial energy use shows that *all* of them report relatively low price elasticities[13-15]. This includes both econometric (or trend-based) models and engineering-based models. Earlier, more aggregate models showed larger elasticities because of *apriori* "consistency constraints," databases ending in 1974, and failure to account for the detailed *structure* of industrial demand as it varies from time to time and place to place.

If population should grow much beyond present levels in the U.S., there will probably be an *additional* source of energy demand for desalinization of water, which some cities in California already are getting into; with anything like a population doubling, desalinization could become a big part of where we get water, and the additional energy requirements would be enormous[21].

On balance, if one assumes some minimal level of growth in income per capita, it is hard to imagine a totally "soft" energy economy, without a drastic reduction of population. Given the difficulty of maintaining a complex economy on a small engineering base, I would question the feasibility of this. A dramatic improvement in international communications (requiring both advanced technology and cultural shifts) might increase our effective engineering base, but even so I find this scenario hard to visualize. If there *is* any hope for this scenario, it would require drastic reductions in population growth, not only in the U.S., but—for the sake of stability—worldwide.

Coal and Nuclear

The conventional wisdom in energy forecasting says that we will shift, first, to a coal-based economy and then, as the coal grows more expensive, shift more to nuclear. Coal may be used more in the developed world and nuclear more in the developing world, for political reasons. Many long-range forecasting models simply assume that coal and nuclear are available in unlimited quantities.

The conventional wisdom may well be right. However, there are severe environmental problems with both fuels, which will make this transition less than automatic. There are national security issues on the nuclear side which merit more serious action than we have seen as yet.

The environmental consequences of using coal have received a lot of attention. For example, many people associate coal with sulfur dioxide, which they associate with acid rain, which they associate with the massive recent dieback of trees in Germany—a true environmental disaster. Careful studies by the Germans[16-17] suggest that nitrogen oxides (NOx) may actually be the most important pollutant responsible for this damage (and for high ozone levels). About 40% of the NOx emitted in the U.S. comes from motor vehicles, and about 50% from large boilers burning coal. Fuel-cells cars would eliminate the 40%, but conventional, affordable pollution control technologies would have only a marginal impact on the 50%. Fortunately, there has been great progress in clean coal research,[18] which could solve this problem, and probably even save money in the process, at least for new boilers. What to do about existing boilers is a harder problem. The government is already spending billions on clean coal technology, and it is clear that strenuous efforts on these lines must be continued or expanded if we really want to clean up ozone and make a safe, economical transition to coal. Likewise, it is clear that a lot of private capital would be required to build the new plants, and that the federal budget deficit—as described in the overview—will have a big effect on capital availability.

In the long-term, there are two other concerns about coal: (1) it contributes to greenhouse warming (more so than natural gas, but far less so than shale oil); (2) it is in finite supply. If the world relied *entirely* on coal, if we maintained economic growth, and if we avoided using environmentally questionable forms of coal (or depended on undiscovered coal speculated on by officials in Communist countries), then coal might last somewhere on the order of six to ten decades.[19-20] This may seem like forever to some people, but the development of safe alternatives might also take many decades; in any case, the sooner we stop the accumulation of greenhouse gases, the better. It is not too soon to think about the transition away from coal.

Nuclear power has often been advocated as a sustainable alternative to fossil fuels. However, a huge amount of research would be needed, at a minimum, to make this technology acceptable to the public. Furthermore, it is clear that existing controls on nuclear proliferation have not been effective enough to prevent major emerging problems in the Mideast (Iraq/Israel and India/Pakistan) and elsewhere. As recently as 1983, nuclear power accounted for only 3.3% of world energy supply.[5] Studies for the Second Report to the Club of Rome[21] showed graphically how huge an increase in that industry would be required to supply all the world's energy needs, especially if one allows for population and economic growth in developing nations and the eventual need for breeder reactors. The opportunity for nuclear weapons proliferation and terrorism is directly proportional to the availability of nuclear materials for diversion; a growth by orders of magnitude in civilian nuclear power would lead to a similar growth in the potential for diversion. If the number of political actors with access to nuclear weapons increases by orders of magnitude, and if the new political actors are more diverse in their motivations than the old ones (e.g., include crazies), then the probability of a first use of a nuclear weapon would increase by orders of magnitude as well. There are many scenarios for what could happen after such a first use, ranging all the way from global horror and authoritarian repression through to a greater willingness of other actors to use nuclear weapons. (Herman Kahn has pointed out how many other weapons went through similar cycles in the past, from religious revulsion through to widespread use and death.) It is not clear whether high civilization and vigorous economic growth would be sustainable under any of these scenarios.

Some analysts hope that a new form of nuclear energy—controlled fusion—would solve all this. But after decades of research, the future of fusion as an affordable source of energy now seems debatable, and major budget cuts have resulted from the debates. Known forms of fusion produce neutron radiation just as much as fission does, and the most economical form of fusion would probably be a hybrid fission-fusion reactor, leading to all the same national security problems. Breakthroughs in fundamental nuclear science, such as neutron-free "cold-fusion," may yet be possible, but should certainly not be counted on.

From a forecaster's point of view, the nuclear path may well be the most likely path (after a short recess), and the hazards of nuclear proliferation have already begun to yield serious consequences. This underlines the need for more conscious effort and heavy investment to open the doors to any real alternative, for the sake of national security.

High-Tech Renewables

Beyond coal and nuclear technologies, there is one family of technologies which does *not* face the tight upper limits which affect the soft technologies: high-tech renewables, such as direct solar. Simple physical calculations show that a modest fraction of the U.S. land area would be quite enough to sustain all of our energy needs. Many years ago, DOE published a program plan for solar cells in which they would achieve economic competitiveness at least for peak power (e.g., noon time in the summer) by the end of this century. For many years, the actual price reductions actually exceeded the DOE plan, as one might expect from a solid-state technology which is a cousin to microchips and PCs; however, after drastic cuts in the DOE budget for solar cells, and cuts in private research due to falling oil prices, the prices of solar cells flattened out. Progress is still going on, but is very slow. Work is also going on on more direct solar technologies to produce methanol or hydrogen, through new programs at the Solar Energy Research Institute in Colorado.

In addition, there still remains the problem of what to do about baseline electric power—the bulk of our electricity use. All of the possibilities involve risk and—if they look good on a first evaluation—would still require enormous investments. It is essential to develop technologies which can compete economically with nuclear power, in order to persuade other countries to resist the nuclear path and to avoid even domestic resistance base on price shock (which killed synfuels). There is a vague hope that ground-based solar might become cheap enough somehow to compete with nuclear; however, baseload power generally costs 5 to 10 times less than peak power,[22] and it is questionable whether costs can be reduced that much beyond the present projections. Still, there are new technologies to produce methanol or hydrogen directly using sunlight whose costs are difficult to project. There is also some hope that radically new forms of geothermal energy might work out, with more research. Some people have even hoped for vast amounts of primordial gas deep in the earth's crust, though recent assessments of this are not encouraging. Finally, it is still quite possible that one could generate electricity from solar cells in space, and beam the energy down to earth, at a marginal cost competitive with nuclear power. (This would be better for the environment than ground-based solar, because the microwave receiving zones would require less land per kilowatt-hour than solar cells, in part because of 24-hour operation; also, low-level microwaves have only a higher-order effect on plant life, at the most, while cutting off light simply kills them.) From a sheer engineering point of view, the last of these alternatives is easier to visualize,[23] but it would require the development of cheaper space transportation systems, such as a second-generation National Aerospace Plane, and automated lunar mining technology; such technologies are within the range of what we now know,[24] but would require an enormous amount of effort. It would require not just money, but an effort to avoid wasting the money on distractions. In any case, when no *one* technology is guaranteed of success, the safest path is to fully explore a *variety* of them, even if it does cost more money to do so.

Even if we successfully switch to these advanced technologies, there will still be limits on the population which we can sustain comfortably and efficiently in the United States, because of land costs and water pollution.

The cost of high-tech energy will depend critically on the cost of land. The cost of land *near people* is a critical issue, because of transmission and maintenance costs. Real estate costs in urban and suburban areas are already an economic burden to many people, and a doubling or tripling of population would make this phenomenon more pervasive across the country; this in turn would certainly raise the cost of land, and the cost of solar energy. Reductions in population from the present level would reduce land prices in some areas, but the effect would not be so pervasive. (Perhaps a population reduction would allow more people to move to areas which receive more sunlight.)

On the environmental side, high-tech renewables are much more benign that the status quo, but they are not problem-free. Even today, in California, there are major concerns about ground water contamination, much of which has been traced to gasoline stations, to chemical plants, and even to computer manufacturers. Replacing gasoline with methanol would not change the overall magnitude of the problem (though methanol is more biodegradable), and a big increase in population density would presumably increase the concentration of pollutants. Likewise, high-tech renewables would not prevent undesirable byproducts in most chemical plants or chip factories, and it would not prevent plastic bags from choking fish in lakes or oceans. Given that the problems today are already a concern, it would seem very worrisome to imagine increases in population which could double or triple the scale of the problems.

Conclusions

This essay has only touched the surface of some very difficult and complex issues.

The transition to sustainable sources of energy will require a whole series of major transformations in the economy, each costing billions of dollars, each entailing major risks, and requiring serious attention now. Failure to make a timely or benign transition would lead to serious problems for national security, the environment and longer-term economic growth. Successful transitions would require major government investment in accelerated R&D, stronger incentives to the private sector, and trillions of dollars in investments from the private sector; all three of these will be hard to come by in the coming years, if the present deficit environment persists. Any population policy which encourages investment and reduces the growth in the nonproductive population would have an *immediate* impact on the growth of the federal deficit, and help a great deal in increasing the probability of a successful transition away from oil. In the long term, the energy sector and the environment would probably be healthiest if the U.S. population were somewhere around 50 to 100% of the present level, in my view. If one were very optimistic about biomass and international cooperation, and pessimistic about high-tech renewables, then the optimum would be more like 60 million people.

If the issue of population growth is neglected, then, as the essay by Bouvier has shown, it may be difficult to avoid a doubling or even tripling of U.S. population, which would clearly pose problems for energy and the environment, due to higher land costs and water pollution.

FOOTNOTES:

[1] The views expressed in this essay are personal judgements, and do not in any way reflect the official view of my employers, past or present.

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