Land, Energy, and Water

The Constraints Governing Ideal U.S. Population Size

BY DAVID AND MARCIA PIMENTEL

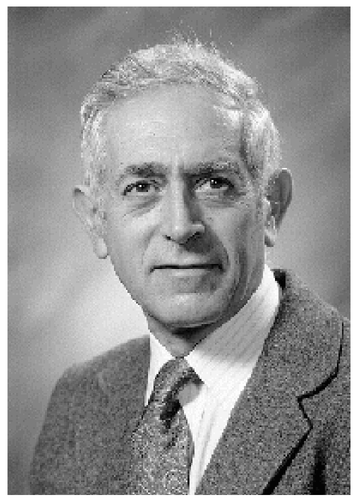
One frequently hears that U.S. agriculture is the most efficient in the world. It is so, indeed, if measured on the scale of output per hours of labor input. It is, however, very inefficient if measured in terms of output per unit of energy input. Like most agriculture, it is diminishing its own base through loss of topsoil, and the intensive use of fertilizer and pesticide poses a threat to groundwater sources, wetlands, and fisheries.

Along with air and water, agriculture supplies the first tier of human wants, and U.S. agriculture is of particular importance, because it has helped to fill the gap in food production in much of the world. Given the constraints on future energy availability that have been dramatized (again) by the Kuwait crisis, an examination of the connections between energy, food production, and sustainable agriculture provides a particularly appropriate starting point for the effort to define optimum U.S. population size.

For most of this century, leading scientists, public officials, and various organizations have been calling attention to the rapidly growing human population and the deteriorating environment throughout the world.

Based on these assessments, genuine concerns arise about maintaining prosperity and the quality of human life in the future.

In the United States, humankind is already managing and using more than half of all the solar energy captured by photosynthesis. Yet even this is insufficient for our needs, and we are actually using nearly three times that much energy or about 40 percent more energy than is captured by all plants in the United States. This rate is made possible only because we are temporarily drawing upon stored fossil energy. We are approaching the end of the petroleum era, however, and other fossil fuels are not inexhaustible. Moreover, the very use of these fossil fuels, along with erosion and other misuse of our natural resources, is reducing the carrying capacity of our ecosystem.



Professor David Pimentel

These are not sustainable conditions, and our natural resources cannot be expected indefinitely to maintain a population as large as the present one, without a remarkable decline in our living standards.

Thus far, our society appears unable to deal successfully with problems of the environment, resources, and population. It has a poor record of effectively managing and protecting essential environmental and natural resources from overexploitation due to ignorance, mismanagement, and the impact of growing human numbers. Recent history suggests that these problems have been escalating,

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moreover, because the United States has not clearly acknowledged that the attainment of an unspecified but high general standard of living depends on the interaction of the environment, resources, and population density.

Decisions concerning the environment and natural resources that are made in the United States, and indeed throughout the world, are ad hoc in nature and designed to protect or to promote a particular or immediate aspect of human well-being or the environment, or both. All too often, solutions are sought only after a problem reaches a crisis status. As Benjamin Franklin wrote long ago in *Poor Richard's Almanac*, "it is not until the well runs dry, that we know the worth of water." Based on experience, it will not be until the pressure of human population on the environment and resources becomes intolerable that some corrective action will be taken by individuals and governments. But then it may be too late to avert hunger and poverty.

In this article, we examine the degradation of the environment, the consumption of nonrenewable resources, population growth, and the possible decline in U.S. prosperity. We also suggest that dramatically reduced U.S. population densities would ensure individual prosperity and quality of environment for future generations. With sufficient information and understanding of our problems, we may be able to create sound policies.

Resources and Population Density

Each country in the world is unique in its resources of fertile land, forests, water, and energy, as well as its topography, temperature, and rainfall patterns. These and other factors influence the productivity of the people, their food supply, their economic and social welfare, and even to some degree their political security. Innate human behavior exhibits a strong will to survive and achieve some level of prosperity and quality of life. The specific characteristics of the desired standard of living vary from person to person. Nonetheless, compared with those who have a relative wealth of resources, people inhabitating regions with fewer natural endowments must struggle harder to achieve the living standard they desire. Yet for both, large population size and rapid population growth lessen the availability of the vital resources and stress the sustained functioning of all components of the environment.

Foods and Feed Grains Consumed per Capita (in Pounds) per Year in the United States and China

Food/feed	USA[a]	China
Food grain	152	592[b]
Vegetables	246	450[c]
Fruit	139	24[d]
Meat and fish	227	55[d]
Dairy products	583	7[d]
Eggs	33	13[d]
Fats and oils	62	13[d]
Sugar	145	13[d]
Total	1,587	1,128
Feed grains	1,762	141[b]
Grand total	3,349	1,269
Kilocalories/person/day	3,500	2,484[e]

[a]USDA, 1985. Converted from kilograms (1 kg = 2.2 lb.).
[b]Total grain production per capita in 1985 was 364 kg (802 lb.) (CDAAHF, 1986). It is estimated on the basis of some unpublished data that 8.5 percent of the total grain production was used for seeds and industrial materials, 17.5 percent for feed, and 74 percent for food (Wen, personal communication, 1987).
[c]Estimated on the basis of total vegetable planting area (Wen, personal communication, 1987).
[d]CDAAHF, 1986.
[e]CAA, 1986.
Source: D. Pimentel, L.M. Frederickson, D.B. Johnson, J.H. McShane, and H.-W. Yuan, "Environment and Population: Crises and Policies," in *Food and Natural Resources*, D. Pimentel and C.W. Hall, eds. (San Diego: Academic Press, 1989).

A comparison of some aspects of life in the United States and China reveals startling extremes and suggests what Americans can expect if our population continues to grow at its current rate. Despite the government's policy of one child per couple, with a population of 1.1 billion, China is growing at a rate of 1.4 percent or 15 million per year. The population of the United States currently stands at 252 million and is growing at a rate of about 0.8 percent per year (depending on one's estimates of emigration and illegal immigration). However, if the number of immigrants coming into the United States is allowed to increase, the rate of U.S. population growth will escalate.

China, with a land area similar to ours, is already experiencing diminished per capita supplies of food and other essential resources, as well as a deteriorating natural environment, as evidenced by the great deforestation and intense soil erosion. The relative affluence presently enjoyed by Americans has been made possible by our abundant supplies of arable land, water, and fossil energy relative to our present population numbers. As our population escalates, our resources will inevitably experience pressures similar to those now experienced by China.

Statistics suggest that we in the United States produce and consume about forty-seven times more goods and services per capita than do the Chinese. Currently, approximately 3,300 pounds of agricultural products are produced annually to feed each American, while the Chinese make do with only 1,300 pounds per year. To produce food for each person in the United States, a total of 4.7 acres of cropland and pastureland is used, whereas in China only 0.9 acres per person is used. Each person in China eats essentially a vegetarian diet, one that is low in animal protein. The Chinese have nearly reached the carrying capacity of their agricultural system. In contrast, the average U.S. diet is varied and high (66 percent) in animal protein foods.

Since colonial times and especially after 1850, Americans have relied increasingly on energy sources other than human power for their food and forestry production. Relatively cheap and abundant supplies of fossil fuel have been substituted for human energy. Fossil-based fertilizers and pesticides, as well as machinery, have made our farmers more productive while diminishing the level of personal energy they must expend to farm. The Chinese have not been as fortunate; they still depend on about 500 hours per acre (h/a) of manual farm labor; compared with only 4 h/a in the United States.

Resources Used per Capita per Year in the United States and China to Supply Basic Needs

Resources	United States	China
Land (acres)		
Cropland	1.5[a]	0.2[b,c]
Pasture	3.2[a]	0.7[b]
Forests	3.2[a]	0.2[b,d]
Total	7.9	1.1
Water		
(gallons x 103/yr)	661	122
Fossil fuel		
Oil equivalents		
(gallons)	2,114[f]	109[g]
Forest products		
(tons)	15[a]	0.03[c,d]

[a]USDA, 1985. [e]USWRC, 1979
[b]Wu,1981. [f]DOE, 1983.
[c]Smil, 1984. [g]State Statistical Bureau PROC, 1985.
[d]Vermeer, 1984.

Note: Figures converted from metric in sources. I hectare = 2.47 | acres. I liter = 0.2642 gallons. I metric ton = 1.1023 tons.

Source: D. Pimentel, L,M, Frederickson, D.B. Johnson, J.H. McShane, and H.-W. yuan, "Environment and Population: Crises and Policies," in *Food and Natural Resources*, D. Pimentel and C.W. Hall, eds. (San Diego: Academic Press, 1989).

Industry, transportation, heating homes, and producing food account for most of the fossil energy consumed in the United States. Most fossil energy in China is used by industry, a lesser amount for food production. Per capita use of fossil energy in the United States amounts to about 2,100 gallons of oil equivalents per year, or twenty times the level in China.

Status of U.S. Environmental Resources

Basic to making decisions about our future is the need to assess both the quality and quantity of land, water, and energy, and the biological resources we will have at our disposal in coming decades. At our present population level of 757 million we are affluent consumers of our vital resources. However, in the face of increasing demands due in part to a growing population, many of these resources are being depleted, with no hope of renewal after the next one hundred years. Although these components function interdependently, they can be manipulated to make up for a partial shortfall in one or more. For example, to bring desert land into production, water can be applied to the land, but only if groundwater or river water is available and if sufficient fossil energy is available to pump the water. This is the current practice in California and many other western states, enabling some of our western agricultural regions to be highly productive.

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Land, that vital natural resource, is all too often taken for granted, yet it is essential for food production and the supply of other basic human needs, such as fiber, fuel, and shelter. Currently, Americans use about 1.5 acres per capita of arable land per capita to produce our food. Nearly all the arable land is in production, and in fact some marginal land is also in production. Thus, Americans do not have new arable land to open up to take care of a growing U.S. population.

At present the soil on U.S. cropland is eroding at rates that average 8 tons per acre per year. This is of particular concern because soil reformation is extremely slow; specifically, we are losing topsoil sixteen times faster than replacement. Even now, in what used to be some of our most productive agricultural regions, soil productivity has been reduced 50 percent, and in some areas it has been so severely degraded that it has been abandoned.

All arable land that is currently in production, and especially marginal land, continues to be highly susceptible to degradation. Although some marginal land has been withdrawn under the Conservation Reserve Program, other marginal land cannot be removed from production, because it is essential to feed Americans. Certainly, more effort should be made to implement soil and water conservation practices on both arable and marginal land.

Despite serious soil erosion, U.S. crop yields have been maintained or increased because of the availability of cheap fossil energy for inputs like fertilizers, pesticides, and irrigation. Currently on

U.S. farms, about 3 kilocalories (kcal) of fossil energy are being spent to produce just 1 kcal of food. Our policy of supporting this 3:1 energy ratio has serious implications for the future. One cannot help but wonder how long such intensive agriculture can be maintained on U.S. croplands while our nonrenewable fossil energy resources are being rapidly depleted.

In addition to use in agricultural production and throughout our entire food system for processing, packaging, and transportation, fossil energy is used to fuel diverse human activities. Overall fossil energy inputs in different economic sectors have increased twenty to one thousand fold in the past three decades, attesting to our heavy reliance on this energy.

Projections of the availability of these energy resources are not encouraging. In fact, a 1989 Department of the Interior study reports that, based on the most current oil-drilling data, the estimated amount of oil resources has plummeted. This means that instead of having about a thirty-five-year supply of oil, we are limited to a sixteen-year supply if use remains at about the current rate. Concurrently, natural gas, another important energy resource, is being rapidly depleted and nuclear energy is also limited because uranium resources face eventual depletion. Reliable estimates indicate that coal reserves are sufficient to last for more than a century. However, larger populations can be expected to put additional stress on use of all energy resources. Thus, considering population growth and the forecasts about our nonrenewable energy supplies, all efforts need to be focused on conserving current supplies while intensifying research on developing new energy sources.

Along with land and energy supplies, we take water supplies for granted and often forget that all vegetation requires and transpires massive amounts of water. For example, a corn crop that produces about 112 bu per acre of grain will take up and transpire about 450,000 gallons per acre of water during just one growing season. To supply this much water to the crop, not only must 1 million gallons (40 inches) of rain fall per acre, but it must be evenly distributed during the year and especially during the growing season.

Of the total water currently used in the United States, 85 percent is used in agriculture, while the remainder is needed for industry and for public use. In the future, the rate of U.S. water consumption is projected to rise both because of population growth and because of greater per capita use. The rapid increase in water use is already stressing both our surface and our groundwater resources. Currently, groundwater overdraft is 25 percent greater than its replenishment rate, with the result that our mammoth groundwater aquifers are being mined at an alarming rate. In addition, both surface and groundwater pollution have become a serious problem in the United States, and concern about the future availability of pure water is justified.

Threats to Those Resources

Pollution is pervasive throughout our environment and degrades the quality and availability of resources like water, land, air, and biota (life forms). For example, when salts are leached from the land during irrigation (up to 8 tons of salts per acre during the growing season) and deposited in rivers, the effectiveness of this river water for further irrigation is reduced.

Air pollution has a more pervasive impact than water pollution. In the United States, the estimated 23 million tons of sulfur dioxide from factories and cars that are released into the atmosphere annually cause serious environmental problems in both our natural and agricultural environments. For example, acid rain, produced in part from sulfur dioxide, is having major environmental impacts on aquatic life in streams and life in U.S. forests.

Furthermore, a wide array of chemical pollutants is released to the air, water, and soil and is already adversely affecting the growth and survival of many of the 500,000 species of natural plants and animals that make up our natural environment. For example, each year about 550,000 million tons of toxic pesticides are applied to control pests, but all too often they kill beneficial species as well. Some of these pesticides leach into groundwater and streams, damaging the valuable plants and animals that inhabit surface waters.

In addition to toxic chemicals, the conversion of forests and other natural habitats to croplands, pastures, roads, and urban spread in response to expanding population numbers is reducing the biological diversity of plants and animals. These natural biota are vital for the recycling of organic wastes, the degrading of chemical pollutants, and the purifying of water and soil. They are also the essential reservoirs of genetic material for agriculture and forests.

Transition from Fossil to Solar Energy

Instead of relying on the finite supplies of fossil energy, we must focus research on ways to convert solar energy into usable energy for society. Many solar energy technologies already exist, including solar thermal receivers, photovoltaics, solar ponds, and hydropower as well as the burning of biomass vegetation. Using some technologies, moreover, biomass can be converted into the liquid fuels ethanol and methanol.

As recently as 1850, the United States was 91 percent dependent on biomass wood and solar power for energy. Gradually that has changed, until today we are 92 percent dependent on fossil energy, while biomass energy makes up only 3 percent of the fuel we use.

Looking to the future, reliance on biomass energy use undoubtedly will grow and again become one of our dominant forms of solar energy. However, use of biomass has major limitations. The total amount of solar energy captured by vegetation each year in our country is about 13×10^{15} kcal. This yield including all the solar energy captured by agricultural crops, forests, lawns, and natural plants, cannot, according to all estimates, be increased to any great extent. Furthermore, the total solar energy captured by our agricultural crops and forest products is about 7×10^{15} kcal, or slightly more than half the total solar energy captured. Because this portion of biomass energy provides us with food fiber, pulp, and lumber, it cannot be burned or converted into biomass energy.

Biomass vegetation provides the food and shelter for a wide variety of important natural biota (life forms) that help keep our natural environment healthy. Some of these species recycle waste and nutrients; others help clean our air, soil, and water of pollutants. Without sufficient biomass, these essential processes would stop.

Another factor to consider is that only 0.1 percent to 0.2 percent of the total solar energy per acre can be harvested as biomass in the temperate region. This is because solar energy is captured by plants only during their brief growing season, and for three-quarters of the year most plants are not growing. The use of relatively large land areas and large capital equipment investments will be needed for the conversion of biomass energy into usable form.

Land Resource Requirements for Construction of Energy Facilities That Produce 1 Billion Kilowatt-hours per Year of Electricity for a City of 100,000 People

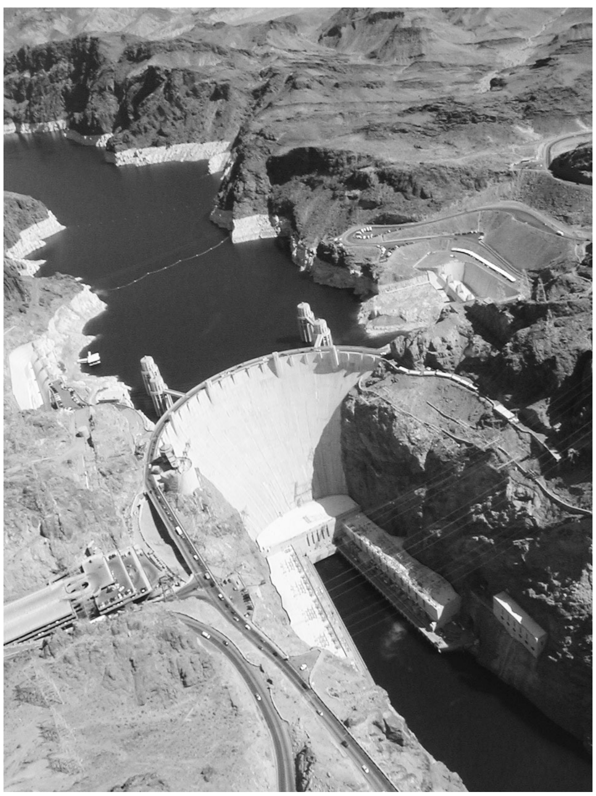
Electrical Energy Technology	Land in Acres
Solar thermal central receiver	1,976
Photovoltaics	1,482
Wind power	6,670
Hydropower	32,110
Forest biomass	815,100
Solar ponds	22,230
Nuclear	168
Coal	222

Source: D. Pimentel, L.M. Frederickson, D.B. Johnson, J.H. McShane, H.-W. Yuan, "Environment and Population: Crises and Policies," in *Food and Natural Resources*, D. Pimentel and C. W. Hall, eds. (Academic Press, San Diego, 1989).

Even at our present population level, to sustain our lives and activities we are burning 40 percent more fossil energy than the total amount of solar energy captured by all plant biomass. Clearly, our consumption of resources, especially nonrenewable fossil fuels, is out of balance with our supplies. The plain fact is that we are depleting these resources at an alarming rate and need to find and develop other energy sources.

However great the investment we are prepared to make, the availability of land will be the major constraint to the expanded use of solar energy systems. Almost three-quarters of the land area in the United States is already devoted to agriculture and commercial forestry, so only a relatively small percentage of our land area is available for harvesting biomass and other solar energy technologies to support a solar energy-based U.S. economy.

The amount of land required to provide solar-based electricity for a city of 100,000 people illustrates the land constraints. Providing the needed 1 billion kilowatt hours per year from wood biomass would require our maintaining 815,000 acres of permanent forest, as shown in the table on page 55. Even hydropower is, in part, land based, because on average it requires 32,000 acres of land for an adequate size reservoir. Furthermore, the land used for the reservoir is often fertile, productive agricultural land. Both solar energy and hydropower have serious land and environmental limitations. Compared to biomass and hydropower production, nuclear and coal-fired power plants, including mining, require relatively small areas of land.



An aerial view of Hoover Dam in the Black Canyon of the Colorado River. When completed in 1935, it was the world's largest electric power generation station and world's largest concrete structure.

The conversion of biomass into energy, such as corn into liquid ethanol fuels, unfortunately requires enormous inputs of fossil energy. For example, about 1.5 gallons of oil equivalents are used to produce 1 gallon of ethanol equivalents. Thus, under optimal conditions about 70 percent more energy is used to produce ethanol than there is energy in the ethanol produced. Even if we quadrupled efficiency so that 1 kcal of fossil energy produced 2 kcal of ethanol, about 10 acres of corn land would be required to fuel one U.S. automobile per year.

If we make the optimistic assumption that the amount of solar energy used today could be increased about three- to ten-fold without adversely affecting agriculture, forestry, or the environment, then from 3 to 10 x 10^{15} kcal of solar energy would be available. This is at best only one-half the current level of energy consumption in the United States, which is about 20 x 10^{15} kcal and averages 2,100 gallons of oil equivalents per capita per year. One possibility is that fusion energy will eventually be developed and make up the shortfall. However, odds for this happening in time are about 1 in 1,000. Furthermore, the intense heat its production generates would have to be overcome.

Toward a Sustainable Agriculture

Analyzing the 120 gallons of oil we now use to produce food on one acre of land suggests ways we might decrease that fossil-based energy expenditure. Both fertilizers and pesticides are lost or wasted in agricultural production. For instance, about $18 billion per year of fertilizer nutrients are lost as they are eroded along with soils. Further, livestock manures, which have five times the amount of fertilizer nitrogen used each year, are underutilized, wasted, or allowed to erode along with soil. Much fossil energy could be saved if effective soil conservation methods were to be implemented and manures were used more extensively.

Another waste occurring in agriculture that affects energy use can be attributed to pesticides. Since 1945 the use of synthetic pesticides in the United States has grown thirty-three-fold, yet our crop losses continue to increase. More pesticides have been used because agricultural technology has drastically changed; for example, crop rotations have been abandoned for many major crops. About 40 percent of our corn acreage is now grown continuously as corn, and this has resulted in an increased number of corn pests, Despite a thousand-fold increase in use of pesticides on corn-on-corn (continuous corn), corn losses to insects have risen four-fold.

Improved agricultural technology and a return to crop rotations would stem soil erosion, conserve fertile land, reduce water requirements for irrigation, and decrease pesticide and fertilizer use, thereby saving both fossil fuels and water. With relatively small populations, more land is available for cultivation. The use of more land to produce food reduces the total energy inputs needed in crop production and would make agriculture more solar energy dependent and sustainable. For example, instead of raising a given crop on one acre with an energy input of about 120 gallons of oil, the use of two acres for the same crop would make possible a reduction in energy inputs from 50 percent to 66 percent.

This, of course, assumes the availability of sufficient land, and a halving of yields per acre. Some estimates suggest that if losses, waste, and mismanagement were eliminated, we would be able to produce present yields of food on the same amounts of land with one-half the energy outputs and still have a more sustainable system. This should probably be considered an upper limit. Since supplies of arable land cannot be much expanded, and since we have already hypothesized the diversion of some land to solar energy uses, prudence suggests that, in planning any such shift to sustainable practices, we anticipate lower yields and lower total production. This, in turn, forces a choice between a smaller population or one that is less well fed.

Prosperity and Population

If the United States were to move to a solar energy-based economy and become self-sustainable, what would be our options and levels of prosperity with a self-sustaining solar energy system replacing our current dependency on fossil energy? The energy availability would be one-fifth to one-half the current level. If the U.S. population remained at its present level of 252 million, a significant reduction in our current standard of living would follow, even if all the energy conservation measures known today were adopted.

If the U.S. population wishes to continue to enjoy its current high level of energy use and standard of living and prosperity, its ideal population should be between forty and one hundred million people.

With sound energy conservation practices and a drastic reduction of energy use per capita to less than one-half current usage, it might be possible to support the current population. One choice requires a significantly lower population level, and the other results in a dramatic reduction in the standard of living because of the resource needs of the larger population. On the positive side, we do have sufficient fossil energy, especially coal, to help us make the needed transition in the use of energy resources and population numbers over the next century, provided we can manage to lessen the environmental impacts now damaging our ecosystem.

Conclusion

At present levels of fertility and migration, the U.S. population will rise by more than one-half by 2050. A modest increase in fertility could drive it past a half-billion, and we would be heading toward population densities like those in present-day China. Comparisons to China clearly show why the

United States will be unable to maintain its current level of prosperity and high standard of living, which are based on its adequate fertile land, water, energy, and biological resources. Supplies of fossil energy, a nonrenewable resource, now are being rapidly depleted, and in just a few years, most U.S. oil resources will be used up. Fortunately, natural gas reserves will last for nearly fifty years, while coal reserves will carry us beyond the next century.

Therefore, we must start now to make the slow transition from our dependence on fossil fuels to the development of solar energy power as our major energy resource. For the United States to be self-sustaining in solar energy, given our land, water, and biological resources, our population should be less than 100 million—significantly less than the current level of 252 million. If, however, the current population level is sustained, a drastic reduction in standards of living will follow.

The available supply of fossil fuels, especially coal, will provide the time we need to make the necessary adjustments involving new solar energy technologies and agriculture practices. Coupled with this, Americans will have time to improve their use of and respect for natural resources and the environment.

With a population of forty to one hundred million, the United States could become self-sustaining on solar energy while maintaining a quality environment, provided that sound energy conservation and environmental policies were in effect to preserve soil, water, air, and biological resources that sustain life. With these far-reaching changes, we feel confident that future generations of Americans would be able to enjoy prosperity and have a high standard of living. Starting to deal with the future before it reaches crisis level is the only way we will be able to avert real tragedy for our children's children. Through education, fair population control, sound resource policies, the support of scientific research, and the effort of all the people, we will be able to face the future with optimism and pride. ■

MOUNTAINTOP REMOVAL

Boulders flee incising blasts.
Whining diesels gather for surgery.
Mastectomy in shale and granite
Shuffled chaos of rubble and silt,
Dusty sloughing of crust, sedge and
saplings
Entomb creek creatures and willows below.
The fragile valley mortally deformed.
Shorn, the knob yields its black viscera
For steel mastodons to grind and gorge.
Unheeding showers wring silted
Sulphuric rivulets from the deflated hill,
The darkening river waits below,
To rush the brew to innocent lips.

I watch with due remorse,
Allayed by my imperious need
To age with the ease that I am owed,
Safe from sting or absence of a fickle sun
Laved in the TV's gaudy narcosis
Of couplings, wails and mirthful violence,
To cook without fire and cool without ice,
Miraculously message and instantly heed
Myriad faceless fellow mountain eaters,
I am one of countless pyrophagic predators,
Always with apologies to be sure,
To peel the arbored pelt from sinless hills
Shred and heap their timeless pillars
In acidic ossuaries on dying burns.
It is my due to fatten
On the primordial black haunches within,
My due to commodify the eternal hills,
To dine on the flesh of my only earth.

—Dave Simcox, 2008