Abstract

Forging a sustainable energy policy is one of America's greatest challenges in the new century. We must develop energy supplies that are clean, "green," renewable, and affordable for the sake of both a healthy environment and a healthy economy. Over the long term, failure to do so could have catastrophic consequences for our environment and our economy, and thus not only our quality of life, but our very survival as a society within an ecosystem. A sustainable energy policy will also look at the demand, and not just the supply, side of the equation. As a result of unprecedented economic and population growth, U.S. energy demand, like most of the world's, has risen sharply since World War II (and even well before that); this has led to rapid, steady increases in the consumption of the fossil fuels – oil , natural gas, and coal, as well as most other energy forms. Such increases cannot continue indefinitely.

This study examines what portion of America's growing energy consumption can be linked to a growing population, that is, an increase in the number of energy consumers in the United States, and what portion can be linked to rising per capita energy consumption reflecting our passion for a plethora of consumer products that use, in total, a prodigious amount of energy. Using a standard mathematical apportioning procedure (explained in the study), the analysis assigns percentages of our rising consumption of total energy, petroleum, and electricity and our output of carbon (that is, carbon dioxide), the major greenhouse gas, to population growth, and by implication, to growth in per capita consumption.

The analysis finds that, with the exception of electricity generation, U.S. population growth explains the preponderance of growth in our national energy consumption. Since the U.S. population, driven primarily by high immigration levels, is projected to continue growing rapidly through this century, with no end in sight, unsustainable, harmful growth in energy consumption can be expected to continue as well, until some combination of energy resource depletion or negative environmental feedbacks and economic turmoil curtail it. Thus, policy makers should recognize that a long-term, sustainable energy policy must incorporate a population policy based on population stabilization, that is, halting further population growth and maintaining our population size within a level that can be sustained in perpetuity by our resources and environment, while still providing for prosperity and a high quality of life.

About the Author

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Population Growth –
The Neglected Dimension of America's
Persistent Energy/Environmental Problems

By Leon Kolankiewicz

Introduction – Why energy is so important (a reminder)

In the simplest terms, physicists define energy as the ability to do work. But this sparse, even humdrum definition does scant justice to the profound meaning of energy to our very existence. It falls short in the same way the definition of sound (a type of energy) as simply "vibratory disturbance through a medium" misses the incredible variety and richness of sounds and the music, communication, language, animal social behavior, human civilization, and emotional responses that sound makes possible.

Energy powers ecosystems as well as economies. Solar energy activates virtually all life, both terrestrial and aquatic, at the earth's surface; it energizes the biosphere, that thin film of living organisms and their inorganic medium that envelops the planetary surface. Hundreds of millions of years ago, green plants evolved the ability to tap into this reliable source of energy through the complex biochemical process of photosynthesis. Using water and carbon dioxide as primary raw materials, the tiny factories called chloroplasts, present in the cells of every green leaf, and containing the pigment chlorophyll, manufacture glucose (a simple sugar or carbohydrate) as a main product and oxygen as a byproduct. The net result is that low-energy (higher entropy) inorganic matter is converted to high-energy (lower entropy) organic matter. Ecologists call green plants "primary producers," because they furnish the fundamental organic foodstuffs upon which all animals in the great chain of life nourish themselves, directly or indirectly. Without green plants to harvest the energy of the sun, quite simply there would be no cows, whales, humans or any other animal.

Solar energy also drives the hydrologic cycle (without which there would be no rain or rivers), winds, large-scale atmospheric circulation patterns, and ocean currents. It provides the heat without which earth's surface would be frigid and sterile.

Deep within the earth's mantle, another kind of energy – nuclear fission, or the splitting of uranium atoms – releases the prodigal quantities of heat that impel the geologic processes of our restless planet, including plate tectonics ("continental drift") and the mountain-building forces of volcanism, earthquakes, and folding/faulting.

The human economy is equally dependent on energy. This should not be surprising, since the human economy is but a subset, albeit an ever-larger one, of the biosphere, or "nature's economy."[1] From the time of ancient hunter-gatherer societies to today's Information Age, humans have always depended on solar energy for all the food we eat and for many other resources that furnish indispensable commodities. Until the industrial revolution two centuries ago, all of our energy was derived from renewable, that is to say solar, sources. Firewood used in cooking and space heating was an indirect form of solar energy, as was the power of draft animals and human laborers. The kinetic energy of moving water had been exploited for many centuries. With the discovery of electricity and its many applications in the eighteenth and nineteenth centuries, by the late 1800's, inventors and engineers were moving swiftly to develop hydroelectricity – impounding water behind a dam, allowing gravity to pull it down through the blades of a turbine, and turning a generator to induce the flow of electrons, that is, produce an electric current or electricity.

Also beginning in the 1800's, humanity began to harness on a significant scale the vast deposits of earth's fossil fuels – first coal, then oil, and finally natural gas. According to accepted geologic theory, these fossil fuels originated hundreds of millions of years ago when complex organic compounds from partially decomposed plants and animals were subjected to millions of years of heat and pressure.[2] These plants and animals lived and died in swampy, aquatic and shallow marine environments and their remains were deposited as sediments, accreting in ever-thicker layers on the anaerobic (oxygen-starved) bottom. Thus, in a very real sense, the fossil fuels amount to a form of congealed solar energy – concentrated, accumulated, and enriched over many millions of years. At present rates, *Homo sapiens* will exhaust in mere centuries the treasure-trove of fossil fuels that took nature tens of millions of years to fabricate.[3] While this by itself is extraordinary, it is perhaps even more staggering that by and large, humanity acts as if it were oblivious to this impending depletion, squandering the fossil fuels as profligately as if they were expected to last – and even meet ever-growing demands – forever.

Two of the more ironclad laws of physics pertain to energy and mass. The First Law of Thermodynamics, sometimes called the Conservation Law, states that the total amount of matter-energy in the universe is constant and unchanging; while energy can be converted into mass and vice versa, the total amount of matter-energy after any such transformation remains unchanged, i.e. is conserved. The Second Law of Thermodynamics is sometimes called the Entropy Law. It states that in every conversion of energy, there are inefficiencies: some energy is invariably lost or dissipated into unusable forms, typically low-grade, "waste" heat. These laws pertain at all scales – from the prodigious energy output of distant galaxies and quasars to the comparatively tiny power produced by a AAA battery in a penlight. They also prevent the development of that classic will-o'-wisp, the perpetual motion machine, that once set into motion will keep operating indefinitely without any external source of energy.

Until those economists and technophiles who fantasize about the human brain as the "ultimate resource" are able concoct a way to repeal or amend these most fundamental laws of nature, human destiny, like that of every other living organism on earth, will in good part be dictated by what these laws permit…and what they relegate to the realm of science fiction. One thing they most certainly will not permit is perpetual growth in raw energy consumption of the magnitude the world has witnessed over the past century, whether these gigajoules are supplied by the fossil fuels, hydropower, wind energy, solar energy, nuclear fission or fusion. Growth may hypothetically be possible for a century or two yet, by running down the earth's natural capital and running up its ecological debt. Ultimately, however, this growth is not sustainable, and will involve unprecedented and potentially ruinous intervention in the cycles, flows, stocks, sinks, and processes of the biosphere that sustain all life on earth, including that of *Homo sapiens*.

U.S. Energy Primer

In the United States, total energy consumption more than tripled over the past half-century, jumping from 32 quadrillion Btu's (32 quads) in 1949 to 99 quads in 2000. (The Btu is the traditional English unit for measuring energy content. It is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. One quadrillion or 1,000,000,000,000,000 Btu is sometimes referred to as a "quad," a convention that will be followed here.) The lion's share of our energy comes from the fossil fuels – oil, natural gas and coal – and fossil fuel consumption nearly tripled over the same period, from 29 to 84 quads.[4] In 2000, of the primary energy derived by combusting fossil fuels in the United States, 45% was from petroleum, 28% from natural gas, and 27% was from coal. Figure 1 shows the 1949-2000 trends in the consumption of the three fossil fuels and other energy forms. Figure 2 depicts rising consumption and production of overall energy in the United States over the same period. It shows that today, domestic energy production is less than consumption, primarily because of the inability of declining domestic petroleum production to meet increasing domestic petroleum consumption. (The gap is made up by rising oil imports, which now account for over half of U.S. petroleum consumption.)

In the late 1950's a promising new source of energy was exploited commercially for the first time – nuclear power. For the first couple of decades after being brought on-line, controlled fission of uranium to boil water and generate electricity was widely heralded as the clean, cheap future of electric power. But construction and maintenance costs began to skyrocket in response to unresolved safety and environmental issues. At the same time, nagging questions about waste disposal and nuclear proliferation arose and would not go away. Then came two infamous accidents: Three Mile Island near Harrisburg, Pennsylvania in 1979 and Chernobyl in the Ukrainian Republic of the USSR in 1986. Both of these, particularly the latter reactor core meltdown, badly shook public confidence in the operational safety of nuclear power plants. Of the two, Chernobyl was by far the worse in terms of actual casualties, including hundreds or thousands of deaths, a sharp increase in thyroid cancer among children in the Ukraine and neighboring Belarus, the permanent evacuation or relocation of more than 360,000 nearby residents, and the rendering uninhabitable (to humans) of 4,300-square km area.[5] Ironically, the exclusion of people from the radioactive zone has been a boon to wildlife much more than the radiation appears to have been a bane.[6]

As a result of all its technical, economic, environmental and political setbacks, in recent years the increase in nuclear-generated electricity in the United Sates has slowed considerably. From 1970 to 1980, nuclear electric power generated grew from 0.24 to 2.74 quads, an 11-fold or 1000% increase. By 1990, it had grown to 6.16 quads, more than a doubling (125% increase) in the previous decade. In the 1990's, it continued to grow, but at a much slower rate, to 8.01 quads (a 30% increase), and its share of total U.S. energy consumption crept up from 7% to 8%.[7] The country currently has 103 commercial nuclear power reactors but no new ones have been ordered by American utilities since the 1970's and in the coming years some of the operating plants may be shut down as they approach and exceed their engineering design life.

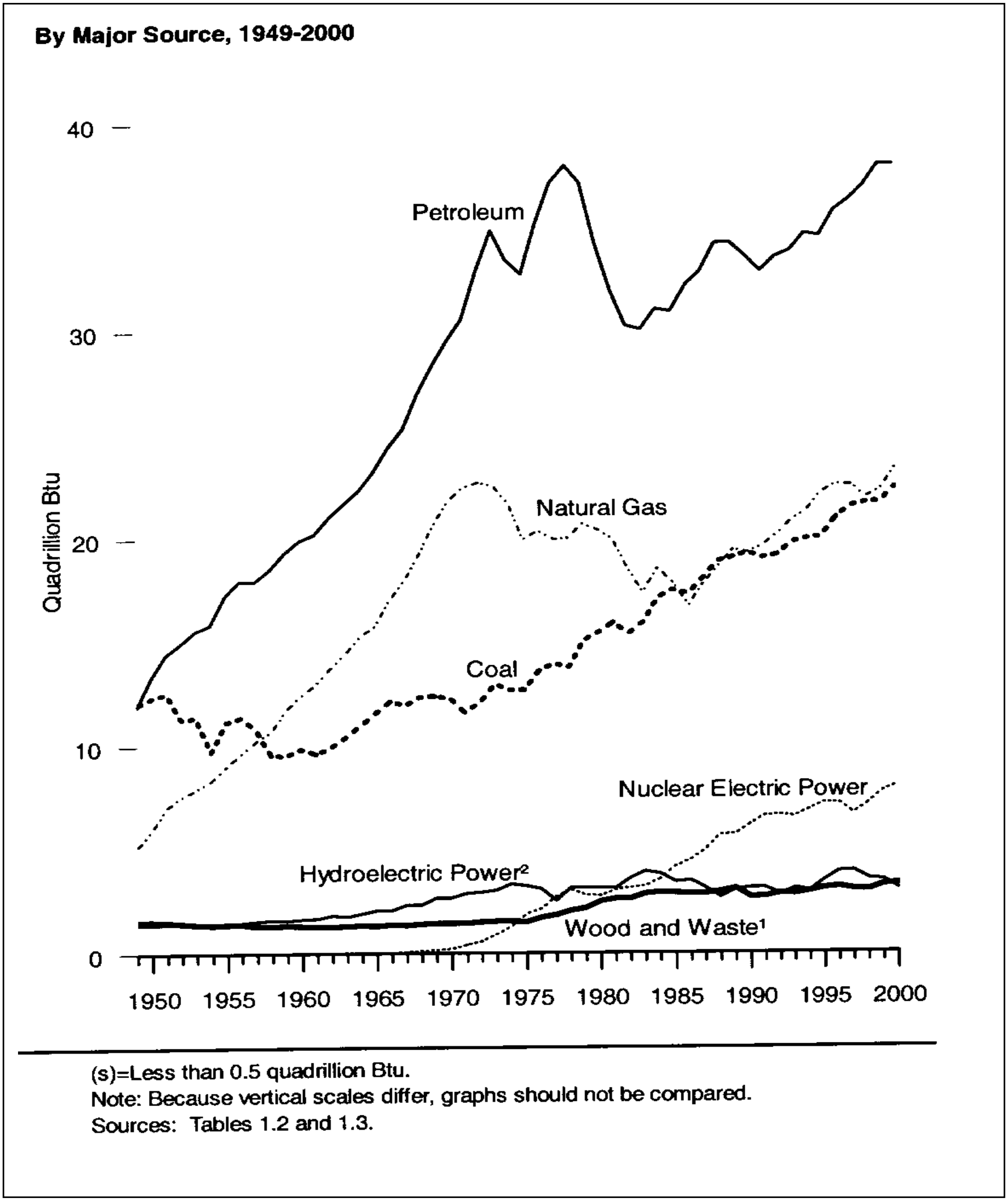


Figure 1 – U.S. Energy Consumption by Source, 1949-2000

Source: Energy Information Administration. 2001. Annual Energy Review 2000. *Figure 1.3*

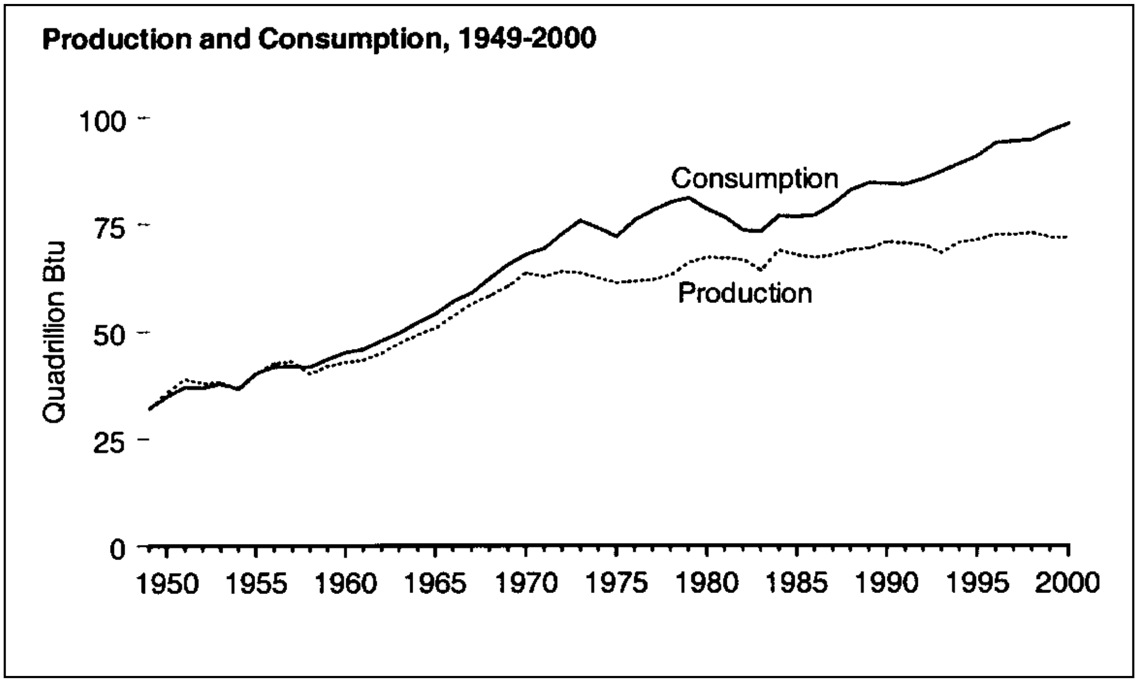


Figure 2 – U.S. Energy Production and Consumption, 1949-2000
Source: Energy Information Administration. 2001. Annual Energy Review 2000. *Figure 1.3*

It is safe to say that, in the post-World War II era at least, most Americans never gave much thought to where their energy came from and how secure and durable those sources were until 1973-74. In October 1973, that blissful ignorance was shattered when the ever-simmering Arab-Israeli conflict in the Middle East boiled over into war once again. Most of the world's oil reserves lie in Arab nations, and Saudi Arabia, in particular, because it holds the largest petroleum reservoirs of any single country in the world, plays a decisive role in setting world prices. U.S. support of the Israelis triggered an Arab oil embargo against the United States, cutbacks in production overall, and a sharp jump in prices on the world market.[8] In early 1974, Americans were outraged at the tripled or quadrupled prices they paid for gasoline at the pump as well as having to wait in long lines just to buy the stuff. We had always taken filling our gas tanks for granted, and the growth in large gas-guzzling automobiles on American roads reflected this illusion. But with domestic crude oil production having peaked in 1970 and domestic consumption continuing to rise unabated, oil imports now accounted for about 39% of our consumption.[9] An uncomfortable sense of vulnerability to unpredictable, unstable foreign forces gripped Americans. This was to be the first of two "energy crises" that convulsed America and the world. The second occurred in 1979-80, related once again to Middle East unrest, this time from the fundamentalist Islamic Revolution in Iran.

These events spawned both considerable debate in the USA over energy policy and considerable research and practical action on better ways to produce, use and conserve energy. On the policy front, there was a serious examination of alternative sources of energy supply as well as the extent to which energy conservation and efficiency could or should help demand match supply. Investigation of energy supply alternatives ranged across the board: from "hard" sources like conventional coal (surface and underground), synthetic fuels, frontier oil and gas, enhanced oil and gas recovery, oil shale, tar sands, different types of nuclear fission reactors, and breeder reactors using plutonium, to the "soft" sources like centralized and decentralized solar thermal and photovoltaic, passive solar heating, wind, tidal, geothermal, and biomass.[10] Then there were the more exotic sources like nuclear fusion and orbiting solar panels. American entrepreneurs, governments, consumers, and do-it-yourself readers of *Popular Mechanics* concocted and implemented hundreds of clever ideas for saving energy, among them better home insulation, weather-stripping, home energy audits, compact fluorescent light bulbs, more fuel-efficient autos, 55-mile per hour speed limits, appliances that used less electricity, and so forth. Car advertisements on TV included EPA gas mileage ratings as a regular feature.

One consequence of all these efforts was a reduction in demand for energy in the United States, and in particular for imported petroleum. Total U.S. energy consumption actually *fell* from 76 quads in 1973 to 73 quads in 1983, while consumption of imported oil dropped from 13.5 to 10.7 quads over the same period.[11] Annual energy consumption per capita declined from 359 million Btu in 1973 to 314 million Btu in 1983. As the law of supply and demand would predict, this helped bring about a drop in the price of oil. At the same time, the higher oil prices in the 1970's spurred greater exploration and production of crude oil. These factors combined to cause a temporary "oil glut" and a precipitous decline in the price of crude oil in the 1980's. Oil prices, both by the barrel and at the pump, remained relatively low in both the eighties and nineties, as measured in constant dollars.[12]

Unfortunately, the baby was thrown out with the bath water. While lower energy prices may be better for American consumers and the economy in general, at least in the short term, they undermine the timely pursuit of long-term alternatives to oil in the inevitable post-petroleum era. By the late 1980's, the national commitment to energy conservation and innovative or renewable energy alternatives had faded faster than a seabird in an oil slick. More recently, even growing concern about the contribution of burning fossil fuels to climate change (global warming) has not been enough to convince American consumers, politicians and businesses to look at energy policy holistically and with a long-term perspective. Nor to recognize that over the long haul, energy conservation and efficiency are not merely commendable but ineffectual expressions of private virtue (as expressed by Vice-President Dick Cheney early in 2001 when he headed up the Bush administration's energy policy task force), but rather the cornerstone of any viable, *sustainable* energy strategy.

While eminent petroleum geologists like Colin Campbell, Walter Youngquist, Richard Duncan, L.F. Ivanhoe, Craig Bond Hatfield, and Kenneth Deffeyes continue to warn that global petroleum production will likely peak in the first decade or two of the 21st century,[13] American consumers continue to splurge as if there were no tomorrow. As long as gas is cheap today, they would prefer to indulge in their gas-guzzling SUV's, minivans, and pickup trucks rather than conserve oil and the climate for tomorrow. The widening gap between our domestic petroleum production and consumption is depicted in Figure 3. In this, we see that petroleum imports first surpassed domestic production (i.e. exceeded 50% of our consumption) in about 1996.

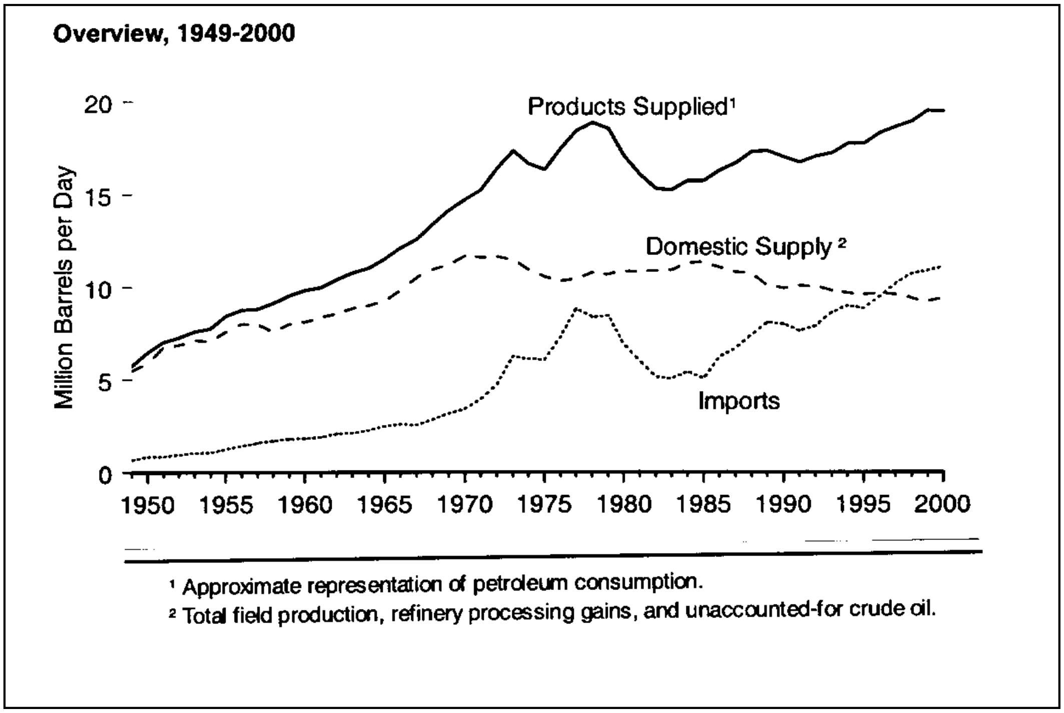


Figure 3 – Domestic Petroleum Production and Petroleum Imports, 1949-2000
Source: Energy Information Administration. 2001. Annual Energy Review 2000. *Figure 5.1*

It needs to be stressed that humanity will never exhaust every last drop of petroleum in the world, but not because it is limitless. Smaller, deeper, remoter pockets of oil will likely remain untapped even after the Oil Age has ended simply because they are too expensive to reach and extract. The financial expense of doing so is only part of the true energetic expense: the cost in physical terms of exploiting the fuel. At the point where the "energy profit ratio" declines to below 1.0 (that is, the energy resource yields less gross energy than the energy needed to procure it, so that net energy is negative) it no longer makes sense to continue exploiting the fuel.[14] While societies can subsidize such exploitation on a limited scale for a limited time, it is physically impossible do so sustainably and on a large scale.

Unlike oil, the lion's share of natural gas and coal consumed in the U.S. comes from domestic production, as a result of the difficulties and costs inherent in the transport of these two fossil fuels over very long, i.e. transoceanic, distances. Domestic natural gas production expanded from 5.4 quads in 1949 to 19.7 quads in 2000, a nearly 4-fold increase, while coal production rose from 12 to 23 quads over the same period, a near-doubling. Neither gaseous fuel nor solid fuel possess the versatility of liquid petroleum, but they can both be burned readily in thermal power plants, and thus in recent decades, they have displaced much petroleum in electricity generation. In 1973, burning coal generated 848 billion kilowatt-hours, natural gas 341 billion kilowatt-hours, and petroleum 314 billion kilowatt-hours. By 2000, coal had grown to 1,965 billion kilowatt-hours, and natural gas to 596; petroleum, however, had declined to 109 billion kilowatt-hours.[15] The United States has vast coal resources but a much more constrained supply of natural gas.

The major renewable energy sources include hydroelectric, solar, wind, geothermal, and biomass. Hydro, wind and geothermal are used primarily to generate electricity, while solar and biomass are exploited both for electricity and space heating. Unfortunately, higher prices, limited, intermittent, or diffuse supply, institutional and financial barriers, and (especially in the case of hydroelectricity) environmental constraints, have slowed the penetration of renewables into the marketplace. In the year 2000, all renewables combined accounted for just 9% of total energy produced in the U.S., of which three-quarters or more was conventional hydroelectric power, maligned by environmentalists for its devastating impacts on rivers and salmon. As a result of these severe drawbacks and the fact that so many rivers in the USA outside Alaska have already been dammed, there is little potential to expand hydroelectric generation from new dams on new segments of river. However, there remains some untapped potential for increasing total hydroelectric generating capacity by retrofitting existing facilities.

At times, in touting their preferred energy solutions, renewable advocates sound every bit as over-exuberant and "cornucopian" as nuclear power advocates were once criticized for being. For example, in a recent special issue of the publication *Voices from the Earth* (Southwest Research and Information Center, Albuquerque, New Mexico) devoted to renewable energy, a section called "Renewable Energy FAQs" [Frequently Asked Questions] asked "What is the ultimate potential of renewable energy use?" and answered "**Limitless!**" [boldface in original]. Another answer claimed, without citation, that **"…it is estimated that all the energy needs of the U.S. could be provided with a land area impact of less than 0.5% of U.S. land area."** [boldface in original].[16] Claims that renewable energy is essentially unlimited in quantity and that its environmental impacts are negligible deserve to be treated with as much skepticism as the "too cheap to meter" claim nuclear power advocates once made so confidently.

Overview of Energy and the Environment

The means by which we produce and consume energy has myriad, profound implications for the environment. This section summarizes the more pronounced effects of the major forms of energy.

<u>Petroleum</u>

Virtually all phases of exploiting petroleum resources entail some type of environmental impact(s), including exploration, extraction, transport of crude oil, refining, transport of petroleum products, and ultimate consumption.

The 1989 Exxon Valdez oil spill in pristine Prince William Sound, Alaska, was a vivid reminder for Americans that there is a dark side to the substance that has become the lifeblood of our industrial civilization. Spread by tides and currents, the black slick eventually extended over an area of 10,000 square miles, coating formerly untouched beaches more than a hundred miles away from where the oil tanker struck a reef while its skipper slept off one too many drinks. In the first days and weeks it killed thousands of salmon, seabirds, otters, seals, whales and eagles; its long-term effects are still being studied. This was the kind of incident that opponents of the trans-Alaska (Prudhoe Bay to Valdez) pipeline fretted about and warned against in the debate over its construction in the early 1970's. More than five years after the accident at Prince

William Sound, an ocean kayaker could still report smelling petrochemicals whenever he stepped ashore.[17]

In general, oil exploration and development in wilderness areas damages the environment and destroys wilderness character through the building of roads and industrial infrastructure, the release of contaminants to air and water, and introduction of large numbers of workers, vehicles and noise into formerly rural or even wild settings. Improved access itself can attract further visitors, or in the case of developing countries, settlers, who may proceed to deforest the landscape and decimate wildlife populations. Still, oil extraction would have to be judged significantly less damaging to the environment than extraction of that solid fossil fuel known as coal. And in recent years, technological innovations have greatly reduced the "footprint" of developed surface area on wild country. Directional drilling, for instance, allows exploratory wells to bend underground in different directions and look for oil reservoirs far away from directly beneath the platform and pad.

At the same time, it is disingenuous to argue, as does the Bush-Cheney administration, Alaska senators, and oil companies, that petroleum exploration of the Arctic National Wildlife Refuge (ANWR) would impact only a tiny fraction of this vast wild sanctuary. Surely most would agree that a single knife slash across the Mona Lisa would damage the integrity of the entire painting, and not just the 2% of the surface area it actually rips through. Similarly, a pristine wilderness cannot have a major industrial operation inserted into its midst, even if only 2% of its ground surface area is directly affected, and still remain intact and unblemished. Much of the debate has centered around whether oil development would impact calving of the huge Porcupine caribou herd, and if so, its adverse effects on the traditional lifestyles and subsistence hunting of the Gwitchin Indians who have utilized this resource for thousands of years.[18] However, even if caribou and other wildlife, such as musk-ox, were completely unaffected by all the proposed activity and infrastructure, the fact remains that the noises, emissions to air, water and land, and the view of scores of workers and vehicles, pipelines, drill rigs, huts, roads, tanks, and all the other appurtenances of oil exploration and development would banish wilderness for the several decades it takes to extract the oil. Even after the oil has been depleted and the area cleaned up, cleared out and rehabilitated, environmental aftereffects will likely be evident for decades if not centuries to come. If this were not the most pristine vestige remaining of what little is left of Wild America, perhaps this outcome would be acceptable to most conservationists.

Nevertheless, on a time scale of centuries to millennia, even the longest-lasting traces of the physical "footprint" of oil development would eventually fade on Alaska's wild North Slope. Arguably, it is global warming itself, to which outcome the burning of fossil fuels pumped out of ANWR would contribute incrementally, that will trigger much more profound changes in the climate and ecology of the area, to the likely detriment of existing species and communities and the benefit of others from more southern climes that will displace them.

Transport of crude oil via pipelines and oil tankers both involve the risk of spills, onto land in the case of the former and into water in the case of the latter. In October, 2001, a vandal fired shots into the Alaska pipeline 107 miles north of Fairbanks, rupturing the pipe and spewing 70,000 gallons of crude oil into the surrounding scrub and spruce forest.[19] Naturally occurring oil seeps have existed for millions of years, and crude oil is, after all, a natural organic substance for which nature has devised physical, chemical and biological means of decomposing. Nonetheless, crude oil and refined petroleum are toxic, and human-caused spills typically release such strong concentrations and large volumes that they cause devastating, if generally temporary and localized, effects on plants, animals, soils and water quality. More oil is dispersed into the marine environment when ballast water is released from oil tankers, but since it is far less concentrated, its effects, if any, are more subtle and chronic.

Refining oil produces great volumes of toxic and hazardous organic chemicals that in the past were dumped willy-nilly into the air and water, creating such noxious zones as "Cancer Alley" along the Mississippi River in Louisiana and the notorious industrial barrens of northern New Jersey and Long Beach, California. Nudged by the federal Clean Water Act and Clean Air Act, pollution control technology has made major strides in cleaning up this industry over the last thirty years. Nevertheless, oil refineries and petrochemical plants are still major producers of smog-generating compounds (nitrogen oxides and volatile organic compounds or VOC's) and toxic wastes that must be regulated.

Burning petroleum products like gasoline, diesel fuel, and home-heating oil generates carbon dioxide (CO_2), carbon monoxide (CO), VOC's or hydrocarbons, and nitrogen oxides (NO_x), as well as other unwanted waste byproducts. In the presence of sunlight, VOC's and nitrogen oxides react to form ozone, which is valuable in the stratospheric ozone layer that protects life from damaging ultraviolet-B radiation, but a potent pollutant in the troposphere or near the ground. And ozone is often measured as an index of smog, that bane of urban, and increasingly rural, air quality. Tailpipe emissions of some of these substances for automobiles have been improved dramatically in recent decades, but one of the gases released, carbon dioxide, cannot really be captured, controlled or converted into anything else because it is simply one of the fundamental products of the exothermic chemical reaction that releases energy. Carbon dioxide is the leading "greenhouse gas," implicated in global climate change and global warming.

NO_x emissions contribute not only to smog, but to acid rain and to the degradation of water bodies like the Chesapeake Bay. NO_x can be converted into nitric acid in the atmosphere; falling to earth, it acidifies unbuffered soils and waters, with consequent adverse effects on trees, plants and aquatic life. Water quality and aquatic organisms in Chesapeake Bay and other coastal estuaries can be damaged by an excess of nutrients like nitrogen, which falls out of the air and can be carried into the bay by its tributaries.

Natural gas

Natural gas is the cleanest-burning of the fossil fuels, emitting fewer conventional or "criteria" pollutants per Btu delivered as well as less CO_2 than either oil or coal. However, natural gas exploration and production entail many of the same impacts on natural or rural habitats as oil drilling, including the potential for a degree of water pollution, habitat fragmentation (from seismic surveys, road building, and well pad construction), soil erosion, and impacts on scenery.[20] Nonetheless, at both the point of extraction and the point of consumption, natural gas is clearly the least environmentally damaging of the fossil fuels. Unfortunately, it too is not unlimited in supply, and the U.S. is already dependent on imports from Canada for a small share of its natural gas consumption.

Coal

If natural gas is the most benign of the fossil fuels, coal is clearly the most problematic, both in the production and consumption phases of its exploitation. While there have undoubtedly been many safety and health improvements in recent decades, at least in the United States and other developed countries with a coal industry, underground coal mines have traditionally been dangerous and unhealthy workplaces. The history of the industry is marred by deadly cave-ins and explosions. Many long-time workers exposed to years of coal dust, inadequate ventilation and lack of proper breathing apparatus have succumbed to black lung disease. An estimated 4.5% of miners are so afflicted, and over 14,000 deaths in the USA from 1979-1996 were attributable to it.[21] Underground mines can also generate acid mine drainage (AMD) from the oxidation of iron pyrite or fool's gold, which is often found in the presence of coal seams. If it reaches surface waters, AMD damages aquatic ecosystems, much as acid rain does, by reducing the pH to levels that many fish, aquatic invertebrates and other organisms cannot tolerate.

Surface or "strip" mines for coal have disfigured countless landscapes in Appalachia, especially in eastern Kentucky and West Virginia. Since the late 1970's, federal law has mandated that landscapes be revegetated and restored to "original contours," but implementation and enforcement have been uneven at best. Furthermore, in recent years, as technology has improved and as thicker coal seams near the surface have been exhausted, in order to reach deeper-lying, high-quality coal beds, the coal industry has resorted to a practice called mountaintop removal.[22] Up to several hundred feet of mountain summits and ridgetops are stripped away with explosives and massive earth-moving machinery called draglines. One of these, dubbed "Big John," stands 20 stories tall and can scoop up 120 tons of dirt and rock in a single bucket-load.[23]

With mountaintop removal, since the volumes of earth are so great, no attempt is made to restore the original landscape; rather, valleys are filled in with this "overburden," and artificial new landscapes are constructed. If the use of coal continues to expand, as conventional energy analysts, electrical utilities, and the current administration propose, this horrific practice, if allowed to continue, will wreak havoc with many southern Appalachian landscapes and remaining natural habitat. In addition, nearby communities, while the beneficiaries of some employment and other economic stimulus from the mining – at least until the coal runs out – also bear the brunt of environmental impacts, and these will last for much longer than the coal does. Colorado is still paying for pollution from mines that closed a century ago.

Nor do coal's problems stop there. Most coal mined (80%) in the U.S. is used in thermal power plants to generate electricity. Two pollutants released at power plants cause serious environmental problems; a third is worrisome. The first is sulfur dioxide (SO_2), which can vary substantially depending on the concentration of sulfur in the coal formations (in general, western coal is lower-sulfur than eastern coal). Sulfur dioxide is related to two grave environmental problems: acid rain (more properly known as acid precipitation or deposition), and reduction of visibility across various areas of the country. The first problem has received more attention from scientists, policy-makers and the public, and has damaged lakes, streams and to some extent forests in parts of the country, particularly the Adirondacks and the Northeast. (The poorly buffered soils of the vast Canadian Shield, the oldest bedrock on the North American continent, which underlies much of Canada east of the Canadian Rockies, are especially vulnerable to acid deposition.)

Sulfur dioxide's second problem, visibility reduction, has compromised the beauty of vast areas of the American landscape, especially in the East.[24] In Shenandoah National Park for example, located in Virginia's picturesque Blue Ridge Mountains, scientists estimate that the average visibility within the park has decreased from about 65 miles a century ago to 15 miles today.[25] Expansive views of ridge after ridge receding to the horizon are now mostly a memory; the ridges disappear instead into a veil of smog. Sulfur dioxide particles or aerosols aren't the only cause of this, but they are the principal one, at least in the East, where SO_2 is estimated to cause some 60-90% of visibility reduction.[26] A good deal of SO_2 can be removed from power plant smokestacks with "scrubbers," but these are expensive and imperfect. Nevertheless, they work well enough that the 1990 Clean Air Act amendments are relying on them as well as an emissions trading program to reduce the nation's overall sulfur emissions, and this is gradually occurring. Whether the emissions will be cut back to a level low enough to avoid or reverse the damage they are causing remains to be seen.

Then there's carbon dioxide (CO_2). Coal emits more carbon dioxide per Btu generated than either oil or natural gas, although each of the fossil fuels releases CO_2 upon combustion. There is a broad consensus among climatologists that the earth's atmosphere is gradually warming and that anthropogenic emissions (both industrial and agricultural) of the so-called greenhouse gases, principally carbon dioxide (CO_2) and methane (CH_4), are responsible.[27] In the mid-1990s, the Intergovernmental Panel on Climate Change (an international committee of earth scientists appointed by the U.N.) predicted that, barring a concerted international effort to reduce CO_2 emissions, moderate population and economic growth over the next century will raise average global surface temperatures by 2°C (4° F) and sea levels by 0.5 meters (1.7 feet).[28] In 2001, the panel issued a new report with even more ominous findings – including an average temperature rise of as much as 10 degrees Fahrenheit – as a result of their conclusion that global warming is happening even faster than earlier predicted.[29]

Early in 2001, a skeptical Bush Administration withdrew from international efforts to implement the 1997 Kyoto Protocol to combat global warming, and asked the National Academy of Sciences to examine the subject. In June 2001, the Academy's prestigious National Research Council issued a report that largely echoed the international scientific consensus. It concluded that the "warming process has intensified in the past 20 years, accompanied by retreating glaciers, thinning arctic ice, rising sea levels, lengthening of the growing season in many areas, and earlier arrival of migratory birds." By the end of the century, if greenhouse gas emissions continue to accelerate, then under *conservative* assumptions of how the climate will react, the average global temperature will rise between 2.5 and 10.4 degrees Fahrenheit (1.4 to 5.8 degrees Celsisus).[30]

What will the ecological consequences of a warmer climate be in the United States? Scientists are only beginning to investigate these complex phenomena, but the possibilities are profound. A national assessment ordered by Congress issued draft findings in June 2000.[31] Among the predicted changes are "potentially severe droughts, increased risk of flood, mass migrations of species, substantial shifts in agriculture and widespread erosion of coastal zones."[32] While agricultural production could increase, due to "fertilization" of the air with carbon dioxide, "many long-suffering ecosystems, such as alpine meadows, coral reefs, coastal wetlands and Alaskan permafrost, will likely deteriorate further. Some may disappear altogether."[33]

It is almost impossible to understate the far-reaching ecological ramifications of climate change. A September, 2001 workshop of scientists and natural resource specialists on vegetation management at Voyageurs National Park in northern Minnesota considered some of these. Certain workshop participants worried that plans to restore the park's majestic stands of red and white pines and other elements of the "transitional boreal forest" to some semblance of their former glory (before decades of logging and fire suppression radically altered forest composition, structure and quality) would be undermined by this type of forest shifting northward beyond the park boundaries in response to rising temperatures. Yet another concern related to the more frequent, violent weather events that are also a predicted consequence of an unstable, warming climate. On July 4, 1999, a massive storm known as a "derecho," with heavy rains and winds exceeding 90 miles per hour, blew down almost half a million acres of forest in northeastern Minnesota, most of it within the legendary Boundary Waters Canoe Area Wilderness.[34] Such storms would especially threaten large, tall trees that protrude high and exposed above the forest canopy. No one knows for sure, but it is certainly within the realm of possibility that groves of grand old giants could largely vanish from American forests if for no reason other than the higher frequency of more fierce storms and gales that knock them down.

As if all this were not enough, power plants burning coal are a significant source of mercury contamination.[35] On average, each 1,000 megawatt coal-fired plant emits approximately 2,200 pounds of mercury annually to the air, which eventually falls out and is deposited onto the land and into water bodies and sediments.[36] The toxic form of mercury is called methyl mercury. It "bioaccumulates," that is, it becomes more concentrated – and thus more toxic – as it moves up the food chain and into animals that eat other animals that eat other animals, such as walleye pike, bald eagles…and human beings.

Thus, depending on one's perspective, it may well be more of a curse than a blessing that the United States is so richly endowed with this particular fossil fuel. At more than 200 billion metric tons, the U.S. has more proved reserves of coal than any other country in the world.[37]

Oil Shale, Oilsands and Tarsands

Known resources of these low-grade fossil fuels are massive. The U.S. has the world's largest oil shale deposits, concentrated chiefly in Wyoming, Colorado and Utah.[38] Petroleum geologist Walter Youngquist notes that "enthusiastic reports on the potential of oil shale abound." The U.S. Geological Survey, for instance, estimated that total U.S. deposits (as opposed to recoverable reserves) contain several trillion barrels of oil[39] -- more than global conventional oil reserves. However, oil shale deposits have proven prohibitively expensive to develop, which to date has stymied efforts to extract and market them over the past 80 years.

Moreover, when the energy costs of mining, transporting, refining and waste disposal are tallied up and included in the energy budget for this energy source, the *net* amount of energy recovered from oil shale is likely to be small. What this does is increase the amount of shale that must be mined and processed for each unit of net energy obtained, which in turn increases the amount of ground that must be dug up, and the area of landscape that must be disturbed. Youngquist estimates that each Btu of net energy obtained from oil shale may disturb up to five times the amount of land as each Btu of net energy from coal. Another major impediment to developing oil shale is that it is a water-intensive process in an inherently water-scarce region – the American Southwest. Finally, if oil shale ever were used en masse, it would have many of the same pollution problems as petroleum and coal, including emissions of VOC's, nitrogen oxides, and carbon dioxide.

Oilsands and tarsands are ancient oil fields that have been exposed by erosion and from which the lighter, more volatile chemical compounds have escaped. Alberta, Canada contains the largest reserves of tarsands in the world -- the Athabasca deposit north of Fort McMurray – which in the mid-1990's were producing at the rate of about 280,000 barrels of oil per day, less than one-sixtieth of U.S. consumption but about 20% of Canada's daily crude oil needs. As with oil sands, the energy profit ratio or net energy is far less than with conventional oil. Three barrels of oil extracted and refined from tarsands yield, in effect, one net barrel of oil. Two of the three barrels are used up in extracting the oil from oilsands or tarsands.[40] As with conventional fossil fuels, both the processing and consumption of oils derived from tarsands generates air and water pollution.

Hydroelectricity

Hydropower furnishes about eight percent of the nation's electricity generation by electric utilities.[41] Its two environmental advantages are that it is "clean" – it does not release carbon dioxide, sulfur dioxide, particulates, or mercury to the air – and somewhat renewable. It is "somewhat" renewable rather than entirely renewable because over a period ranging from decades to centuries, hydroelectric reservoirs (as in the case of all reservoirs) inevitably fill in with sediments, reducing the water storage capacity, and therefore the potential energy and generation capacity of the facility. Thus, while water will continue to flow and generate electricity as long as the earth's grand hydrologic cycle of evaporation, rainfall, and runoff continues to function – presumably for millions of years to come – over the long term hydroelectric power plants will inexorably suffer a decline in generating capacity, which will ultimately match the marked daily and seasonal fluctuations in streamflow.

Another advantage of hydropower is that to some extent, it can be combined with facilities that also provide for flood control, navigation, water supply, and lake-based recreation (fishing, boating, water-skiing, swimming, etc.).[42] These ancillary benefits are very valuable to society.

Hydroelectricity's disadvantages are many, severe and well-documented.[43] The floodplain directly inundated by a reservoir contains nature's most productive forests or farmlands, which are permanently drowned. The valley or canyon flooded by the reservoir may contain exceptional scenic or landscape values which are permanently lost or marred, such as Glen Canyon on the Colorado River (upstream of the Grand Canyon) and Hetch Hetchy Valley in California's Yosemite National Park, both of which disappeared under the rising waters impounded by dams. In the past, dam and reservoir construction displaced thousands of residents in the United States. In this country, these days are over, but in densely-populated developing countries like China, India, and Egypt, recent and ongoing large-scale dam projects entail the permanent uprooting of hundreds of thousands or even millions of farmers and rural inhabitants. In the case of the Nile River, the Aswan dam flooded irreplaceable archaeological treasures thousands of years old.

Hydropower's impacts are not confined to the area inundated itself, but continue downstream all the way to a river's mouth. Since suspended sediments in "transport" are intercepted, settle out, and deposited in the bottom of the reservoir, "hungry" waters released downstream will strip away sediments from shorelines and shallows; for example, since the construction of the Glen Canyon Dam, many beaches have disappeared or been drastically reduced in the Grand Canyon downstream. (In some instances, this effect extends all the way to the ocean – beaches can gradually erode away if they are not replenished with sand and sediments, some of which is furnished by rivers.) The clearer water released from dams tends to favor certain fishes and aquatic invertebrates over others. That some water, if obtained from the bottom of the reservoir, may be much colder and oxygen-starved than waters used to be in downstream segments prior to dam construction; once again, this change in the medium, if substantial enough, has significant effects on the aquatic community.

One of the most notorious effects of dams and reservoirs is on anadromous fish, in particular the Atlantic and Pacific salmon, which return from the sprawling ocean to their home streams to spawn. Not only to dams interfere with upstream migration, an impact only partially mitigated by fish ladders, but they have an even more pronounced adverse effect on the survival of salmon smolt migrating downstream to the sea. Finger-length smolt often have difficulty negotiating the slackwater of reservoirs – for which they were never genetically programmed. They succumb to lake-based predators like trout and they are sometimes sucked into penstocks and ground up in turbines. The Pacific salmon runs (particularly the Chinook or king salmon, largest of them all) of the Columbia River in the Pacific Northwest were decimated when the lion's share of that river was converted from a free-flowing fish factory into a hydroelectric factory. It was a tradeoff that engendered the spectacular growth of the Pacific Northwest by providing cheap electricity.

The reality facing hydroelectricity is that, outside of Alaska, very few untapped damsites with large hydroelectric potential can be developed, because many of the best sites have already been exploited, and the political opposition to damming remaining free-flowing segments of rivers would be intense. The U.S. already has over 100,000 large and small dams,[44] but construction of new ones has slowed considerably, leading some in the environmental community and government to proclaim that America has moved beyond the great dam-building era. There is noteworthy potential in retro-fitting existing dams, especially smaller ones, to generate hydropower, but this additional generation is not likely to substantially boost the nation's overall electric output.

<u>Nuclear fission</u>

The beleaguered nuclear power industry is mired in a morass of economic, political and environment problems that have slowed the domestic advance of this once-promising energy form to a crawl. Still, in 2000 nuclear supplied 23% of the electricity generated by the nation's electric utilities. Including non-utility power producers (such as industrial facilities that generate and use their own electricity), nuclear accounted for 18% of total electricity generation in that year.[45]

The environmental advantages of nuclear power are well worth noting: it produces no conventional air pollutants like SO_2 and particulates, it does not require the permanent flooding of productive or scenic valleys, and it releases no CO_2, the main greenhouse gas. Moreover, uranium mines are not as cruel to the landscape as coal mines. These are important advantages, frequently touted by nuclear power's supporters to a skeptical public that all too often tends to see it as an environmental villain.

Against these pluses must be weighed a number of disadvantages. Underground uranium mines have affected the health of miners, many of them Native Americans in the Southwest. And other American Indians have protested the desecration of sacred lands in addition to the residual radioactivity in uranium tailings piles left behind after mining and milling.[46]

Uranium supplies are not unlimited. The isotope used in American light-water reactors, U-235, comprises only 0.7% of naturally-occurring uranium. Thus, nuclear fission itself cannot be seen as a sustainable technology. So-called breeder reactors, which can utilize U-238 (by far the most abundant isotope of uranium) to produce or "breed" plutonium, the atoms of which can later themselves be split to produce energy. The use of breeder reactors would significantly extend the lifetime of uranium reserves. However, the few experimental breeders to date, in the United States and France, have proved highly complex, tricky, and expensive. President Jimmy Carter canceled the only U.S. breeder reactor a research facility near Savannah, Georgia. Breeders also raise significant concerns about the "plutonium economy," running on one of the deadliest substances known to man (with a half-life of 250,000 years and problematic more for its chemical toxicity than for its radioactive properties) in addition to one that raises global security and nuclear proliferation concerns.

For a number of years, physicists, engineers and policy-makers debated the safety of civilian nuclear power reactors. In the 1970s, the Rasmussen Report, headed by a distinguished MIT professor of nuclear physics, concluded that the probability of a nuclear catastrophe with significant loss of life was exceedingly small. Then came the accidents at Three Mile Island in 1979 and Chernobyl in 1986, and the book on safety had to be rewritten.

In addition, nuclear energy produces low and high-level radioactive wastes that must be disposed of or reprocessed. At present, each nuclear power plant has been storing these wastes in temporary repositories on-site. This is considered but a stop-gap measure, and for decades, the federal government has been investigating a centralized permanent underground storage site in a stable, dry geologic formation. The Department of Energy has selected Yucca Mountain, a remote site on the former Nevada Test Range, 100 miles northwest of Las Vegas, where wastes would be entombed deep underground. The objective of this $58 billion project is to bury 77,000 tons of highly radioactive nuclear wastes from civilian nuclear reactors, and effectively isolate them from the environment for the next 10,000 years – an unprecedented endeavor.[47] Yucca Mountain has been undergoing testing for a number of years, and DOE officials estimate it could be ready to open by 2010. In a case of "NIMBYISM" at a state level, the State of Nevada is fiercely opposed to being made the nation's nuclear waste dumping ground. The Bush Administration and the U.S. Senate have recently given the green light to this project, but Nevada officials and environmentalists are likely to resort to the courts. Environmentalists are trying to convince the public that thousands of shipments of high-level waste will pass near almost every American's backyard en route to Yucca Mountain.

The nexus between peaceful nuclear power and the proliferation of military or terrorist uses of nuclear materials and technology is another concern. With the spread of peaceful nuclear reactors comes the spread not only of materials that can be used to make bombs, but also some of the technical wherewithal for the same.[48] It was this fear that led Israeli warplanes to destroy an ostensibly civilian nuclear power plant under construction in Iraq back in 1981. Although reactor-grade uranium fuel is not sufficient for bombs, by-products of nuclear fission such as plutonium can be diverted into weapons of mass destruction.

As if all of the above weren't enough, the September 11, 2001 terrorist attacks on the Pentagon and the World Trade Center have renewed concerns that nuclear power plants are inviting targets for sabotage or outright attack by terrorists hostile to the United States.[49] And the nuclear reactors themselves are not the only or even most vulnerable target – even nuclear waste is apparently being sought by terrorists looking to assemble a "dirty bomb" – that is, a conventional explosive packed with radioactive waste that would be ejected and spread out in the blast. In the wake of the 9-11 attacks, it came to light that the presumed hijackers looked into using crop-dusters to disperse chemical or biological agents and/or obtaining access to hazardous/toxic materials. The shocking audacity of the attacks in New York, Virginia, and Pennsylvania, carried out precisely to wreak the greatest possible carnage, loss of American lives, and destruction of American symbols, leaves no doubt that certain organizations would stop at nothing damage the U.S. economy and prestige and take American lives.

Wind Energy

Winds are a consequence of the uneven heating of the earth's surface by solar radiation, so in a sense they are yet another indirect form of solar energy. Human exploitation of wind to generate power has occurred for centuries. In the early 1900's, windmills were commonly used in the U.S. to pump groundwater (in the Great Plains, many are still visible today, though no longer in use).[50] Until very recently, the lion's share of America's wind electricity-generating capacity was at just three major sites in California – San Gorgonio Pass east of Los Angeles, in the Tehachapi Mountains north of L.A., and at Altamont Pass on the way to Livermore east of San Francisco Bay. Each of these was developed under the leadership of former California Governor Jerry Brown and his innovative California Energy Commission after the oil price hikes of 1973 and 1979. However, in the last few years, development has begun on wind farms at a number of other sites in a wide variety of states, including Colorado, Iowa, Minnesota, Oregon, Pennsylvania, Texas and Wyoming.[51]

Windmill technology has advanced by leaps and bounds in the last thirty years. Wind turbines and the "farms" of windmill networks are now sophisticated, high-tech apparatus. This technical progress has led to a marked decline in generating costs, making wind energy competitive with conventional sources of electricity generation. The two major technical disadvantages of wind are that it is intermittent (not constant) and dispersed (not concentrated), so that it takes a large land area to generate a given amount of electrical energy. However, as with hydroelectric reservoirs providing multiple benefits (i.e. recreation, water supply, flood control), areas with windmills can still continue to provide for certain other rural land uses, such as agriculture, pasture, and rangeland. Lester Brown, founder of the Worldwatch Institute, claims that in parts of the country like the northern Midwest and certain Western states like Wyoming, many farmers and ranchers would be happy to receive a second income from utilities placing windmills on their property.[52]

The first problem, wind power's intermittent nature, is not a big issue as long as wind is a relatively small part of the mix of generating sources on the electric grid. Once wind power attains a sizeable share of the system generating capacity, the need to develop a means of storing the energy it produces so it can be released when it is needed by consumers will become crucial.

If this problem is not solved, wind's contribution to the nation's electricity supply will be limited. Fortunately, at least one solution does appear to be available and under development: electrolyzing water to produce hydrogen. Hydrogen can be then be stored, transported, and burned as a fuel in various manners.

Pilot projects and the limited commercial development to date have brought to light three principal environmental problems associated with wind: noise, visual impacts, and bird kills. These are now considered briefly in turn:

- Noise – In some instances, very large, high windmills (upwards up 150-200 feet tall) with long blades have triggered complaints from nearby residents about noise. During moderate to high winds, the revolution of the windmill blades produces a loud swooshing sound which can reach objectionable levels. This problem can be mitigated by siting wind machines at least one kilometer from residential areas; in addition, newer designs may reduce turbine generator noise.[53]

- Visual impacts – The best sites for windmills are those that are most exposed to the wind, which include ridges, mountains, mountain passes, and seacoasts. These landscapes are often admired for their scenic beauty. Siting single or multiple windmills in such settings can sharply impair their quality by introducing an incongruous visual element. Concern over such aesthetic impacts has led to opposition to certain windmill proposals by environmentalists themselves. Other less scenic sites with large wind potential, such as the flat Northern Great Plains, are far less likely to encounter opposition on the basis of visual impacts to cherished rural or wild landscapes.

  I myself am a devotee of uncluttered, beautiful countryside. I have seen firsthand the windmills farms in California's Altamont Pass and San Gorgonio Pass, and yet did not find them a blight on the landscape. I have observed the latter many times both from Interstate 10 between the L.A. Basin and Palm Springs, CA and from the summit of Mt. San Jacinto directly above them, and did not think they marred the view. If they had been sited on higher, more prominent ridges or mountaintops, on the other hand, I would not have been so sanguine.

  The visual and aesthetic impact of windmills farms are not a trivial issue, in spite of the efforts of some insensitive environmentalists and wind power advocates dismiss it as such. In Europe, where development of wind energy is picking up speed in countries like Scotland, Denmark and Germany, its effect on historic and bucolic landscapes and "viewsheds" is emerging as a potential limiting factor. One nuclear power supporter finds it incredible that so-called "green" groups can endorse "the ravage of our hills" with these industrial installations, while a senior campaigner for Friends of the Earth admits "The wind industry is as capable of environmental insensitivity as any other."[54]

- Bird kills – Turning windmill blades have been documented to kill birds, especially migrating or soaring raptors, that is, birds of prey like hawks and eagles.[55] The extent of this problem, and how to mitigate it, have yet to be determined, but research is ongoing. Whether this problem can be minimized to a tolerable level by design or operational changes or siting changes is still uncertain. But this disadvantage of wind power has already stifled its development in some places. In the 1990's, a proposal to place windmills in the Long Beach, California harbor was opposed by wildlife conservationists concerned about the effect on the local brown pelican population.

Other less salient environmental problems, such as interference with electromagnetic transmission, "shadow flicker" (from the movement of large windmill blades in bright sunlight, which can potentially cause irritation, disorientation, and seizures in humans), and insect mortality, have been identified,[56] but each of these is amenable to mitigation. The upshot is that wind energy, while clean and renewable, is not entirely "green." It can be a partial solution to our energy supply dilemma, but it is not a panacea offering unlimited prospects for expansion. And as windmills proliferate around the country, they are likely to stir up growing opposition on a variety of grounds. Even wind farms placed offshore are not without controversy. A recent proposal to build a "wind park" of 170 wind turbines, each up to 400 feet high, over a 28-square mile area within Nantucket Sound off the coast of Cape Cod in Massachusetts has generated resistance from some boaters, commercial and sport fishers, marina owners and "seascape" lovers.[57]

Biomass

Biomass takes a number of different forms, including the burning of firewood in residential woodstoves for home heating, the use of hog fuel or woodwaste in sawmills and pulp mills to generate process heat or electricity, and the conversion of crops such as corn or sugar cane into ethanol or methanol to use as a fuel additive.

One of the serious long-term issues confronting biomass is whether some of the products, for instance ethanol and methanol, actually generate any net energy for society. That is, the cultivation, production, and chemical distillation of the crops from which they are derived are so energy-intensive that these processes may actually consume as much or more energy than they yield for the economy.[58] For example, the energy expended to produce one liter of ethanol from corn with an energy content of 5,130 kilocalories (kcal) is 10,200 kcal – a net energy loss.[59] If methanol were used as a substitute for oil in the U.S., 250-430 million hectares (625 to 1,075 million acres) of land would be to supply the raw material, an area far greater than that devoted to cropland. In view of unfavorable chemical and physical realities like these, it is doubtful that ethanol and methanol are either sustainable or renewable energy sources.

Where biomass is a waste product or byproduct of some agricultural or industrial activity, or when crops, such as trees, can be harvested in a truly sustainable manner, then biomass may make environmental sense. But this also establishes a fairly restrictive limit in terms of the amount of biomass energy available to society. Harvesting crop residues as a fuel can expose agricultural soils to wind and water erosion, as well as remove organic materials that add soil structure and essential nutrients from the land that must be replaced by fossil fuel-based fertilizers Biomass energy can also compete with other critical land uses for high-quality land and soils.

Potential environmental drawbacks to biomass include usurping land to produce it – so that a biomass-dedicated unit of land is not available to support other types of plant communities that may have more value for, say, forest products or biodiversity, using polluting or unsustainable inputs like pesticides and fertilizers to assist improve yield, and causing some level of pollution at the point of end use. When woodstoves became very popular in the 1970's and 1980's, their improper use contributed to a good deal of smoke air pollution (especially particulate matter), particularly in confined valleys with limited air circulation. Generally, the combustion of biomass generates more air pollutants than gas, but less than coal.

In sum, while biomass does play an important role in today's and tomorrow's energy mix, its potential to expand is severely constrained.

Solar Energy

Solar energy comes in many different forms, some of which are centralized and some decentralized. Centralized forms include several kinds of solar thermal electricity-generating plants and photovoltaic (PV) plants, which can produce electricity for the electric grid. California has several relatively small-scale pilot projects that have been on-line for more than a decade. Examples of decentralized solar technologies are passive solar space heating, solar hot water heaters, and photovoltaic panels for rooftops and dispersed applications (road signs, telephones, buoys, etc.) Most analysts agree that solar has a bright future, as concerns about pollution, global climate change, and environmental sustainability spread and deepen. Solar energy has little or no emissions of greenhouse gases, sulfur dioxide, nitrogen oxides, volatile organic carbons (hydrocarbons); it does not generate significant quantities of solid waste or water pollutants. On the other hand, solar thermal plants use fairly large amounts of water, comparable to the quantities of similarly-sized coal or nuclear plants.[60]

Solar energy is renewable, and the generation or conversion of the sun's rays into electricity or heat is non-polluting, although production of solar panels does entail the use of certain toxic substances (principally heavy metals). Solar is about as "green" as it gets, but as with wind energy, it is no environmental panacea. The main reason is that solar energy is relatively diffuse or dispersed compared to other energy sources, particularly the fossil fuels and nuclear energy. It is estimated that five acres of land are needed for each megawatt of capacity,[61] or about 5,000 acres (almost eight square miles) for a typical 1,000-megawatt power plant. This means that it takes comparatively large areas to capture a given amount of solar energy. If U.S. energy supply were to be met entirely by solar energy, a sizeable percentage of the country's land area would have to be expropriated for this purpose. One estimate thrown around over the years is ten percent or so. On the other hand, another estimate is that only 60,000 square kilometers, or about 20 percent of Arizona would need to be covered by photovoltaic cells to meet the USA's entire electricity demand.[62]

This is still an enormous amount of land and whether the country could accommodate or accept this degree of appropriation is open to question. Make no mistake, unlike placing wind turbines on a site, the solar panels associated with a centralized generation facility completely alter its ecology and appearance every bit as much as a hydroelectric dam and reservoir transform a river. The native flora and fauna of the site, if not completely displaced, are radically changed and biodiversity reduced or eliminated. If America's Southwestern deserts were to be given over wholesale to solar energy production, it would not take long before some conservationists would begin to oppose conversion of vast areas of wild desert landscape and ecosystems to energy factories as passionately as they oppose any new dams now.

The above discussion applies to solar-generated electricity when constructed as central station systems connected to the electric grid. One advantage of PV is that it can be developed as distributed systems that use little or no additional land, since the panels can be installed on existing buildings or other structures.[63]

Geothermal Energy

Geothermal energy is derived from heat contained in certain geologic formations beneath the ground surface within the earth's crust. Geothermal resources can be exploited for both electrical power generation and direct heat applications. In comparison with other energy sources, geothermal energy has some significant environmental benefits: greenhouse gas emissions are virtually nil (Figure 4); ozone-depleting chemicals from both direct and indirect sources are also negligible; sulfur oxide emissions are virtually zero because, by design, geothermal's modern closed-cycle systems reinject almost everything but the extracted heat; and geothermal facilities demand relatively little land surface area. Within their footprint, they resemble most light industrial facilities.[64]

Geothermal resources differ in many respects, but all involve similar environmental concerns, including air and water pollution, the safe disposal of hazardous waste, siting, land subsidence, and potential adverse effects on rare hydrogeological formations, like geysers and hot springs.[65]

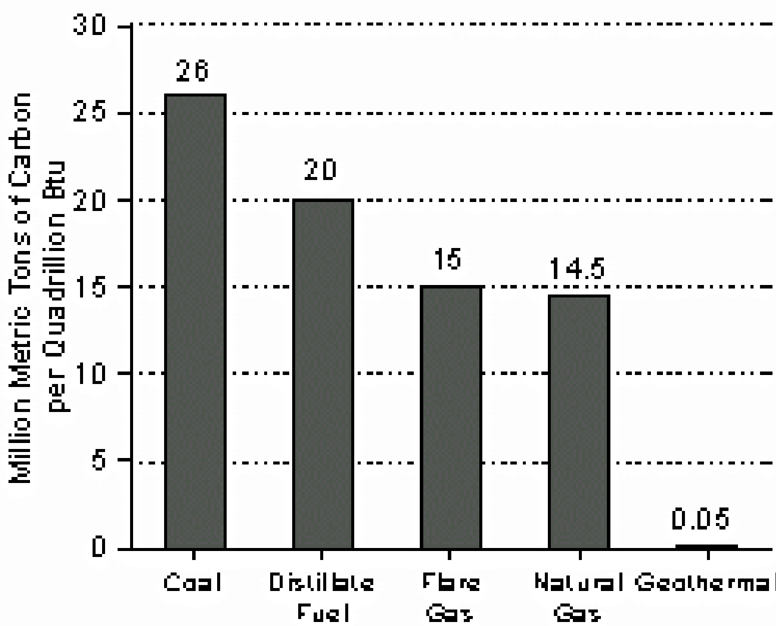
At The Geysers, for example, the USA's largest geothermal facility, steam vented at the surface contains hydrogen sulfide (H_2S), with its attendant "rotten egg" smell, as well as other pollutants, including ammonia (NH_3), methane (CH_4), and carbon dioxide.[66] Nevertheless, for each kilowatt-hour of electricity or quad of energy generated, the amount of carbon dioxide released is still only a tiny fraction of the amount emitted by a coal- or oil-fired power plant (Figure 4).

Scrubbers can reduce air emissions but result in a watery sludge with elevated levels of sulfur and vanadium, the latter a potentially toxic heavy metal. Still more sludge is produced when hydrothermal steam is condensed, and dissolved solids precipitate out. This sludge is usually high in silica compounds, chlorides, arsenic, mercury, nickel, and other toxic heavy metals.[67] Many of these wastes can be reinjected back into a porous stratum of a geothermal well, taking care that they are injected well below freshwater aquifers to avoid groundwater contamination. Such reinjection may also help avert land subsidence. Most geothermal power plants will require a large volume of water for cooling. Where water is scarce, this demand could conflict with other water consumers like agriculture, industry, municipalities, and residences.

As with several other energy sources, one drawback of geothermal energy is that many hydrothermal reservoirs are located in or near outstanding natural areas like Yellowstone National Park (home of the world's most famous geyser, "Old Faithful") and the Cascade Mountains. Proposed developments in such areas have been intensely opposed by environmentalists and wilderness advocates.[68] Not only can such facilities compromise wilderness values, but they can also disrupt the "plumbing" that geysers and other surface hydrothermal features depend on. Thus, the potential for substantial future expansion of this energy resource is uncertain. If hydrothermal-electric development is to expand much further in the United States, reasonable compromises will have to be reached between environmental groups and industry.

Nonetheless, the U.S. Department of Energy asserts that development of geothermal energy has minimal adverse environmental impacts compared to conventional energy sources.[69]

Figure 4 – CO_2 Emissions by Fuel



Sources: Geothermal: China Lake Naval Air Weapons Station, Geothermal Program Office (China Lake, CA, 1996). Other Fuels: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1995*, DOE/EIA-0573(95) (Washington, DC, October 1996), Table B1, p. 98.

The Role of Population Growth

How much of our rising energy demand is due to: 1) increasing per capita consumption, from such energy-intensive devices as SUV's, air conditioners, second homes and larger homes, the expanded industrial capacity needed to generate increased volume and variety of consumer goods, as well as all manner of home electronic gadgetry that didn't even exist 20 years ago (e.g. microwave ovens, VCR's, home computers, the Internet), and how much is explained instead by, 2) an increase in the number of energy consumers, that is, population growth?

Using a straightforward mathematical method elucidated in a paper published a decade ago, it is possible to apportion shares of the growth in aggregate energy consumption to per capita growth in consumption and to population growth, that is, to show what percentage of the growth is associated with or due to increasing per capita consumption and what percentage is related to increasing population.

The generalized mathematical formula for quantifying the respective contributions of population growth and increasing consumption per capita in the growth of any type of resource consumption was laid out in a 1991 paper – "Population and the Energy Problem" – by physicist John Holdren.[70] Although Professor Holdren's paper dealt specifically with the role of population growth in rising energy consumption, the method is based on well-established mathematical principles, and can be applied to virtually any type of resource. For example, it has been applied to the case of urban sprawl, that is, the conversion of rural to urbanized land by growing populations with growing average per capita appetites for the land resource.[71]

The following algebraic equations describe the apportioning method developed by Holdren:

A society's aggregate energy consumption at any given time or period of time can be expressed as follows:

$$E = Pe \qquad (1)$$

Where:

E = total energy use,
P = population size
E = per capita energy use

If over a period of time Δt the population increases by an increment ΔP and per capita energy consumption increases by an increment Δe, then growth in total energy use is given by the following equation:

$$E + \Delta E = (P + \Delta P)(e + \Delta e) \qquad (2)$$

In turn, the increment of growth ΔE can be expressed by equation (3), in which E has been subtracted from both sides and Pe substituted for E on the right side of the equation:

$$\Delta E = Pe + e\Delta P + P\Delta e + \Delta P\Delta e - Pe \qquad (3)$$

$$= e\Delta P + P\Delta e + \Delta P\Delta e \qquad (4)$$

Dividing through equation (4) by E and substituting Pe for E in the terms on the right side of the equation then yields equation (5).

$$\Delta E/E = \Delta P/P + \Delta e/e + (\Delta P/P)(\Delta e/e) \qquad (5)$$

Examining equation (5), it is evident that the percentage growth in total energy consumption (100 x $\Delta E/E$) equals the sum of the percentage growth in population and the percentage growth in per capita energy use only if the increments of growth in population and per capita energy use are small enough that the second-order term [$(\Delta P/P)(\Delta e/e)$] can be ignored. Holdren provides the following example of this mathematical condition: If a population grows by 1% and per capita energy use also grows by 1%, then the second-order term is small enough so that total energy use grows by about 2%. On the other hand, if the growth in population over Δt is 100% and the growth in per capita energy consumption is also 100%, then the increase in total energy consumption is not 200%, but 300%. In this case, the second-order term is so much larger that it cannot be neglected.

Thus, over larger periods of time, such as decades, analysts should either, a) use logarithms of the ratios of final to initial values of the two contributing terms, or b) convert the percentages into annual averages to keep them small enough to be approximately additive. This paper uses the former approach:

Population's share of growth =
$$\text{Ln}((\Delta P + P)/\text{P}) / \text{Ln}((\Delta E + E)/E) \qquad (6)$$

That is, the portion of growth in total energy consumption attributable to population growth equals the natural log of the ratio of the final population to the initial population divided by the natural log of the ratio of the final energy consumption to the initial energy consumption. The remainder of this section applies this apportioning method to three key measures of energy consumption and one key measure of a principle waste byproduct from U.S. consumption of fossil fuels:

1. increase in total U.S. energy consumption from 1970 to 2000;
2. increase in total U.S. electricity consumption from 1970 to 2000;
3. increase in total U.S. petroleum consumption from 1970 to 2000;
4. increase in total U.S. carbon emissions from 1990 to 2000.

Table 1 presents the raw data used in the analyses:

Table 1 – Recent Trends in Key Energy-related Variables in the United States

Year	U.S. Population[1]	U.S. Total Energy Consumption[2]	U.S. Electricity Net Generation[3]	U.S. Petroleum Consumption[4]	U.S. Carbon Emissions[5]
1970	203,302,031	67.9	1,532	14.7	NA
1980	226,542,199	78.4	2,286	17.1	NA
1990	248,709,873	84.3	3,025	17.0	1,320
2000	281,421,906	98.5	3,792	19.5	1,490

[1] *Source: U.S. Census Bureau, historical census data on the World Wide Web at* http://www.census.gov/population/censusdata/table-2.pdf and http://www.census.gov/main/www/cen2000.html .
[2] In quadrillion Btu's (quads); *Source: U.S. Dept. of Energy, Energy Information Administration,* Annual Energy Review 2000, *Figure 1.1 and Table 1.1.*
[3] In billion kilowatt-hours; *Source: U.S. Dept. of Energy, Energy Information Administration,* Annual Energy Review 2000, *Figure 8.2 and Table 8.2.*
[4] In million barrels per day; *Source: U.S. Dept. of Energy, Energy Information Administration,* Annual Energy Review 2000, *Figure 5.1 and Table 5.1.*
[5] From fossil fuel consumption (1999), in million metric tons of carbon; converted from carbon dioxide emissions in teragrams on p. 38 of *U.S. Climate Action Report 2002* (U.S. Department of State), released May 2002.

<u>Population Growth's Share of Increase in Total U.S. Energy Consumption</u>

From 1970 to 2000, total U.S. primary energy consumption from all sectors increased by 45%, from 67.9 quads to 98.5 quads. U.S. population grew by 38%, from approximately 203 million to 281 million over the same time period. Utilizing equation (6) above, we get:

Population's share of growth in total U.S. energy consumption =
$\text{Ln}((\square P + P)/P)$ / $\text{Ln}((\square E + E)/E)$ =
Ln ((78 + 203 million) / 203 million) / Ln (30.6 + 67.9 quads / 67.9 quads) =
Ln (281 million / 203 million) / Ln (98.5 quads / 67.9 quads) =
Ln 1.38 / ln 1.45 =
0.322 / 0.372 =
0.866 = 86.6 %

Thus, from 1970 to 2000, U.S. population growth was related to approximately 87% of the increase in total U.S. primary energy consumption. Using the same equation, and breaking down these 30 years by decades, we obtain the following results:

Table 2 – Share of Increase in U.S. Energy Consumption Related to U.S. Population Growth

Decade(s)	Share of Increase in Total U.S. Energy Consumption Associated With U.S. Population Growth
1970-1980	75%
1980-1990	129%
1990-2000	79%
1970-2000	**87%**

In the 1980's, due to advances in energy conservation and improvements in energy efficiency that began in the previous decade, spurred by the two "energy crises" of 1973-74 and 1979-80, per capita energy consumption actually declined in the U.S. This decline occurred largely in response to rising oil prices during the 1970s and early 1980s. At the same time, certain structural changes were happening to the U.S. economy; some energy-intensive manufacturing and heavy industry, like steel, moved overseas to developing countries with lower labors costs, while less energy-intensive service industries expanded.[72] If our population had remained constant, aggregate national energy consumption would have declined as well. However, U.S. population was not constant; it grew by nearly 10% in that decade, sufficient to outweigh efficiency and conservation gains and bring about an 8% increase in total U.S. energy consumption. This is why Table 2 shows population growth accounting for more than 100% of the increase in energy consumption from 1980-90. In the seventies and the nineties, population growth explained approximately three-quarters to four-fifths of the growth in total energy consumption in the United States.

This runs counter to the conventional wisdom that energy-intensive new technologies and/or rising per capita consumption associated with economic growth itself account for our rising energy consumption as a nation. If rising per capita consumption and/or energy-guzzling technologies were indeed responsible for rising energy consumption, then the mathematical apportionment would have calculated shares for population growth well under 50%. This was not the case at all. Thus, the rising number of American residents, each a consumer of energy in its various forms and quantities for a variety of purposes, is a much larger factor in our nation's growing energy appetite than increasing energy consumption per resident.

These results extend and are comparable to those Holdren presented in his 1991 paper, which concluded that population's share in the growth of total U.S. energy use from 1970 to 1990 was 93%.[73]

<u>Population Growth's Share of Increase in Total U.S. Electricity Net Generation</u>

Domestic electricity generation and consumption has grown much faster than overall U.S. energy use since World War II. While total U.S. energy consumption grew from 32 quads in 1949 to 98.5 quads in 2000, a three-fold increase, electricity net generation exploded from 291 billion to 3,792 billion (3.792 trillion) kilowatt-hours over the same time period, a *13-fold increase*.[74] This reflects the increasing electrification of our economy and the proliferation of electricity-using machines, tools, appliances and gadgets that have become seemingly indispensable facets of modern American lifestyles. Except for transportation, all sectors of the economy – residential, commercial, institutional, industrial, agricultural – are finding greater uses for versatile electricity than fifty years ago. Our homes contain electricity-using devices that were rare or unheard-of then, such as air conditioners, television sets and now big-screen TVs, home computers, second refrigerators, and countless appliances and gadgetry. Even agriculture, or "agroindustry," uses much greater quantities of electricity nowadays for such purposes as pumping of irrigation water, indoor "factory farms" for poultry, and dairy operations.

From 1970 to 2000, electricity net generation in the USA expanded from 1,532 billion to 3,792 billion kilowatt-hours, an increase of nearly 150%. Total energy use increased by "just" 45% over those same three decades. Our economy and lifestyles are becoming more electricity-intensive vis-à-vis energy use patterns as a whole. This has a bearing on the shares of increased electricity production and consumption due to population growth and rising per capita consumption shown below in Table 3.

Table 3 – Share of Increase in Electricity Net Generation Related to U.S. Population Growth

Decade(s)	Share of Increase in Total U.S. Electricity Net Generation Associated With U.S. Population Growth
1970-1980	27%
1980-1990	33%
1990-2000	55%
1970-2000	**36%**

With some variation between decades, the share of the nation's growth in electricity generation explained by population growth ranged from just under one-third to just over one-half. Overall, population growth accounted for 36% or just over one-third of the national increase in electricity net generation. That this percentage is much lower than that for total energy consumption (87%) over the same three decades is not at all surprising in view of the much more rapid growth in electricity generation-consumption than energy use as a whole, for the reasons discussed above.

At 36%, population growth is still a significant factor in the growth of the nation's electricity generation, but no longer the dominant factor, as in aggregate energy consumption. In recent decades, a higher and higher fraction of the nation's energy supply has been allocated to the generation, transmission, distribution, and end use of electricity, rather than direct use. For example, instead of coal being burned directly in home furnaces to generate heat, it is now burned in centralized power plants to generate electricity, which is then transmitted and distributed to thousands of homes for a variety of uses, including electrical heating via heat pumps, baseboards, or other means. With losses associated at each step or transformation along the way, this is an inefficient process – the energy actually consumed at the point of end use is much less than the potential energy contained in the original ton of coal. When the energy used to mine, process, and transport the coal to the power plant is included, the overall system inefficiency becomes even more pronounced.

Although per capita electricity consumption has risen throughout the nation as a whole in recent decades, this isn't true everywhere. In California for example, per capita consumption has actually decreased slightly over the last quarter-century. In 1979, it was 7,292 kilowatt-hours; by 1999, it had declined to 6,952 kilowatt-hours. "Twenty years of more gadgets, new toys, and bigger appliances yielded a 5 percent decrease in per capita consumption of electricity," wrote Ric Oberlink of Californians for Population Stabilization in the *San Diego Union-Tribune*.[75] In California, in contrast to the nation as a whole, the state's surging population growth has clearly overwhelmed efficiency improvements and conservation efforts.

Electricity deregulation, shortages, higher prices, alleged price-gouging, brownouts and rolling blackouts have been front-page news and a political hot potato in California over the last couple of years. Unfortunately, the state's rapid population growth is rarely ever mentioned as a cause of rising demand for electricity exceeding lagging generating and transmission capacity.

Population Growth's Share of Increase in Total U.S. Petroleum Consumption

From 1970 to 1990, aggregate U.S. petroleum consumption increased by 33% or one-third, from 14.7 to 19.5 million barrels per day (MBD). The nation's petroleum consumption was actually less in 1990 than in 1980 (17.0 vs. 17.1 MBD), though these decadal figures obscure the true pattern of change in consumption. By 1980, as a result of the two oil price hikes of 1973-74 and 1979-80, the America's net oil consumption had already been stagnant or in decline for several years. It dropped as low as 15.2 MBD in 1983 before renewing its overall post-World War II upward trend, a trend only briefly interrupted by the Persian Gulf War. (In 1949, American petroleum consumption was just 5.8 MBD.)[76]

Table 4 shows the share of the nation's growth in petroleum consumption explained by population growth:

Table 4 – Share of Increase in U.S. Petroleum Consumption Related to National Population Growth

Decade(s)	Share of Increase in Total U.S. Petroleum Consumption Associated With U.S. Population Growth
1970-1980	72%
1980-1990	NA*
1990-2000	90%
1970-2000	**115%**

*Petroleum consumption declined from 1980-90.

As stated above, national petroleum consumption was actually less in 1990 than in 1980, even as U.S. population grew by more than 20 million. Some might interpret this to mean that population growth was unrelated to petroleum consumption, at least in that decade (that is, if increasing population were indeed a cause of increasing petroleum consumption, then petroleum consumption should have actually increased instead of decreasing). But one needs to consider what was occurring then before jumping to such a hasty, simplistic – and erroneous – conclusion. In the 1980's, the nation was reaping the benefits of widespread, concerted efforts begun in the

1970's to conserve energy and use it more efficiently, particularly petroleum, oil and gasoline, as a result of the skyrocketing prices on the global petroleum market. Notably, the nation's automobile fleet became much more fuel-efficient. These efforts more than offset the growth in the number of American consumers of petroleum by sharply curtailing per capita consumption of this critical fuel.

Overall, population growth is related to more than 100% of the growth in national petroleum consumption between 1970 and 2000. This means that if the U.S. population had been stable and non-growing in these three decades, then our national petroleum consumption would have actually declined, due to energy conservation and efficiency improvements. Our dependency upon the politically unstable Middle East for a critical resource and the pressure to drill for oil in sensitive environments like the Florida and California coasts, Rocky Mountains, and Alaska's Arctic National Wildlife Refuge would have been reduced markedly.

The amount of petroleum needed to produce a dollar of GDP declined for several reasons: 1) conservation and energy efficiency improvements, 2) long-term structural change in the U.S. economy, away from heavy industry and toward a "post-industrial," service-based economy, and 3) a specific shift away from petroleum and toward "home-grown" coal and natural gas. Per capita petroleum consumption thus dropped. But America's population growth was large enough to more than offset this decline in per capita petroleum consumption, and forced total petroleum consumption upwards by one-third.

Population Growth's Share of Increase in U.S. Greenhouse Gas Emissions

With each passing year, scientific evidence is mounting that increased anthropogenic emissions of so-called greenhouse gases – including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) – from the United States and every other country in the world appear to be instigating global climate change. Climate simulation models predict that global warming has only just begun, and will accelerate over the coming century. As stated above in the discussion under coal's environmental impacts, the myriad ecological and economic consequences of global climate change, the details of which are still uncertain, are nevertheless profound, far-reaching, and potentially catastrophic. The U.S. generates more greenhouse gases than any other country in the world. CO_2 comprised 82 percent of total U.S. greenhouse gas emissions in 1999, and combustion of fossil fuels (petroleum, coal, and natural gas) accounted for 98 percent of total CO_2 emissions.[77]

Greenhouse gas emissions in the United States from fossil fuel combustion grew by almost 13 percent from 1990 to 2000. U.S. population grew by almost an identical amount – slightly over 13 percent in the same decade. Thus, the increase in greenhouse gas emissions closely matched the increase in population. Applying the formula above, population growth explains 103% of the increase in our greenhouse gas (carbon) emissions from 1990 to 2000.

In spite of this strong correlation, policy-makers, politicians, the news media and even environmental groups consistently overlook the population angle. For example, the introduction and overview of the Bush administration's 2002 *Climate Action Report* states that: "Higher anthropogenic greenhouse gas emissions are a consequence of robust economic growth: higher incomes traditionally promote increased expenditures of energy."[78] No sign of any recognition that 33 million more American energy consumers in the 1990s are likely to increase national energy consumption from fossil fuels, and therefore greenhouse gas emissions.

If the U.S. had actually abided by the reductions in emissions to which the Clinton-Gore administration had agreed in the Kyoto accords (which were never ratified by the U.S. Senate), then U.S. emissions would have had to decline to 7% *below* its 1990 baseline emissions by 2012. Instead U.S. emissions *rose* by 13% in the last decade alone, and will continue to rise sharply under the Bush-Cheney administration's proposed energy and climate policies and de facto population policy. The latter, while it does not explicitly say so, favors rapid population growth by the administration's persistent support of high immigration levels, both legal and illegal.

While the administration's *Climate Action Report* boasts that administration and U.S. initiatives will continue to improve the energy intensity of the economy, i.e. reduce energy use (and therefore greenhouse gas emissions) per unit of economic output or GDP, it also admits that despite this, total U.S. greenhouse gas emissions are projected to *increase by 43 percent* between 2000 and 2020.[79] And U.S. population growth, with the administration evidently favors or is indifferent about, will drive most of this increase in emissions.

Conclusion – Population Growth Raises Energy Use (and its Environmental Impacts) More Than Rising Affluence or Changing Technology

Using the mathematical apportioning method first applied to population growth and energy consumption by physicist John Holdren, this paper shows that overall, from 1970 to 2000, American population growth explained the preponderance of the increase in the nation's overall energy consumption, petroleum consumption and greenhouse gas emissions. Population growth was an important, but not the primary, factor in the country's rising electricity generation and consumption.

Except for the case of electricity then, the lion's share of growth in U.S. energy consumption and related residuals or waste products (i.e. carbon dioxide, the primary greenhouse gas) is related *not* to increasing per capita energy use by average consumers and the economy as a whole – as a result of increased affluence, rising disposable income, and technological advance. Rather, it is related to growth in the sheer number of energy consumers, that is, U.S. population growth. In the 1990's alone, the U.S. population grew by 33 million, more than any single decade in the country's history[80].

Holdren notes that this kind of numerical analysis cannot reveal the whole, complex story of population's role in rising energy consumption, because of "nonlinearities." That is, in the numerical equation, population and per capita consumption are treated strictly as if they were separate, independent variables, and total energy consumption as a dependent variable. In fact, in the real world, each of these variables may interact with and influence one another. In other words, they are likely to be *interdependent* in many cases. In the terminology of systems theory, feedback from a given variable changes inputs to other variables. For example, per capita energy use may depend on a population's absolute size or growth rate, and total energy availability and consumption may affect population growth rates. (One hypothesis is that if it had not been for the tremendous bonanza of the fossil fuels – an enormous, but ultimately limited, stock of energy that could be consumed at very high rates, but *temporarily*, by humanity – then the human population could never have grown six-fold over the last century and a half in the first place.)

But teasing these complexities apart in an effort to quantify the precise role of each factor is all but impossible.

Nonlinearities, lag time, feedbacks, thresholds, synergistic and cumulative effects, and other complexities and uncertainties also thwart attempts to precisely quantify the role of population growth-driven energy consumption in environmental degradation. The earlier discussion indicates the many kinds of impacts that obtaining, producing and using energy has on environmental resources. The size and distribution of the human population is one of the fundamental factors determining the aggregate magnitude of energy extraction, production, and use, as well as the types of energy supply options that are available.

To date, since less than 10 percent of U.S. energy supply is derived from renewable sources, the increasing number of American energy consumers is pushing the country down an ever-more precarious, polluting path of dependency on fossil fuels. Not only will global oil and gas reserves be exhausted for all intents within this century, but their exploitation is altering the earth's atmospheric composition and probably its very climate. Domestic and international coal reserves would last a good deal longer, but mining and burning coal does even more environmental damage, not only to the climate, but to landscapes (strip mining and mountaintop removal), water quality (acid mine drainage and acid rain), air quality (sulfur dioxide pollution and impaired visibility), and wildlife populations and their human users (mercury contamination of raptors and fish).

While it might be technically and economically feasible – with far more commitment than the current administration or Americans in general have shown to date – to transition toward more renewable, "greener" energy sources, thereby avoiding eventual economic and ecological calamity from continuing to squander fossil fuels, none of these renewable sources is cheap, unlimited, or entirely free of environmental problems. If the United States were entirely dependent on renewable energy sources, it would still not be able to support an ever-growing population indefinitely. If anything, living within our energy "income," instead of drawing down our energy "capital," would force the United States to come to terms with population sooner rather than later. It may well be that a genuinely sustainable population capable of being supported in perpetuity by domestic energy resources – while still providing for other goods, services, and amenities, including environmental amenities – would number less than the 285 million Americans alive today.[81]

The U.S. Census Bureau projects more than 400 million by 2050 and somewhere between half a billion to a billion-plus by the year 2100.[82] These ominous projections emphasize that, unless Americans can come to some consensus on an optimal population size for their country and take its now aimless demographic policies into their own hands, instead of regarding population as an uncontrollable juggernaut, then rapid U.S. population growth will continue to be the major factor in several unwelcome energy scenarios, including rising prices, shortages, and continued (even worsening) insults to the environment. And worse specters related to ecological, economic, or financial collapses from misguided energy policy may lurk ahead as well.

U.S. fertility rates have been at or below "replacement" levels (i.e. approximately 2.1 offspring per female) for more than a generation, and thus birth rates are no longer the driving force behind our population growth, unlike the Baby Boom years from 1945 to 1064. Immigration levels, on the other hand, have quadrupled over the last four decades, and are now responsible for 60-70 percent of the nation's population growth. As the demographic momentum of sub-replacement level fertility continues to ebb, U.S. immigration policy will determine virtually all future population growth.

Unless Americans can muster the political will to return to more traditional immigration levels, then population growth will continue unabated for the foreseeable future, and with it growth in national energy consumption and intensifying impacts on the environment and natural resources. However, the "foreseeable future" is not forever, and ultimately, both energy consumption and population growth will come to a halt. Whether this occurs in a more benign manner of our own choosing or a harsher manner if left to nature to impose upon us, remains to be seen.

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