Conservation—not conversation is needed

It's later than we think! Continued exponential growth on energy demand is destructive

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Any energy policy which ignores exponential growth in demand and its consequences on finite resources is not acceptable. In fact, because of this relationship more emphasis needs to be placed on attaining zero growth than on increasing supplies. Conservation which is an absolute precursor of zero growth and not more conversation appears to be the only alternative because it is later than we think!

An analysis of the potential consequences of prolonged, exponential growth at currently established rates in energy consumption and population proves this position. Basic data from authoritative sources, used in grossly simplified calculations, show results that speak for themselves. It should be noted, however, that these results are incomplete because complex interactions between various variables parameters are neglected.

A forecast of what actually will happen is not produced here; rather a delineation is produced of what would happen if current trends are maintained if exponential growth rates and finite resources are considered.

Despite a number of profound studies on this subject which have appeared in the last five years, these authentic efforts have been denigrated by name-calling, such as purveyors of gloom and by other impertinent accusations. Many prefer to be lulled into complacency by estimates of a mind-boggling magnitude for energy reserves, particularly when they are expressed in terms of life span based on current annual consumption rates. We do not like to be reminded how drastically this life span is reduced under conditions of exponential growth. For example, (Fig. 1) an energy reserve which ostensibly has a life of 2,000 years in terms of present annual consumption will last less than 100 years under an annual growth rate of 5 percent which has prevailed for more than a century. Even more startling is the comparison for our so-called, inexhaustible nuclear resources (including all the deuterium in the ocean via fusion) which have been estimated at 5×10^{27} Btu (five billion, billion, billions or equivalent to a million years of sunshine). This resource could presumably satisfy our total energy demand for 20 billion years based on current annual consumption; yet, as will be explained later, under 5 percent per annum growth in demand, nuclear energy wouldn't see us through the next 500 years—most assuredly a finite rather than an infinite resource. Therefore, we should be more concerned with life expectancies for our energy reserves based on exponential growth rather than on present consumption rates.

Exponential growth is akin to compound interest:

$$E = E_o\,(1+0.01r)^n \qquad (1)$$

where E_o = annual consumption in the base year, E = annual consumption "n" years later, and r = percent annual growth rate. (For $r = 5$ percent, the annual consumption doubles every 14.2 years.) The cumulative amount or sum consumed over these "n" years is given by:

$$\Sigma = E_o\left[\frac{(1+0.01r)^{n-1}-1}{0.01r}\right] \qquad (2)$$

which tells us that the consumption during any doubling period exceeds the cumulative consumption in all prior years. Thus, if the energy growth rate is maintained at 5 percent per year between the years 1975 and 1990 (more precisely, the year 1989.2) more energy will be consumed in this interval than in all the years (since day one) prior to 1975.

Here only the potential limits to energy and land re-

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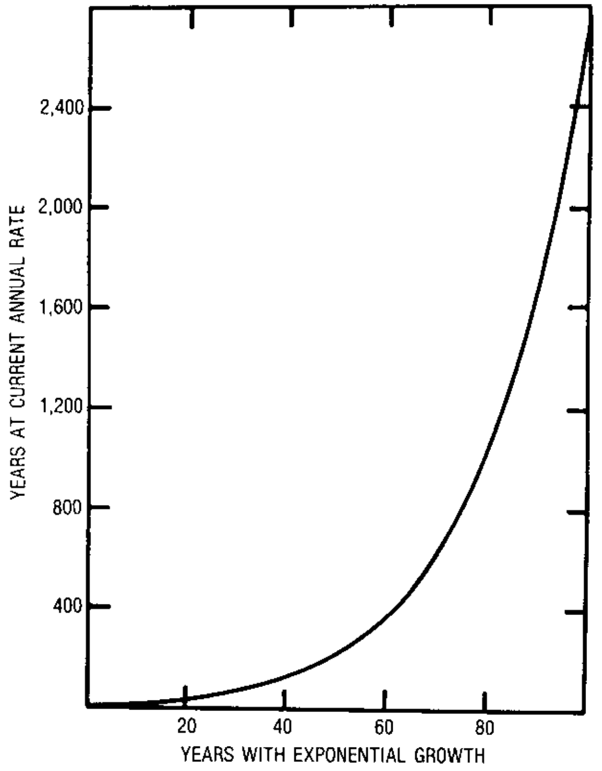


Fig. 1—Effect of exponential growth at 5 percent per annum on life of finite resources.

sources will be considered. Supplies of natural resources such as minerals, potable water and air can be analyzed in a similar manner since they all constitute finite resources which are being eroded by the exponential growth.

A global viewpoint is adopted for two reasons:

- As energy, food and land shortages grow more acute, it is unlikely that any nation will be "permitted" to revel in isolation; to speak of independence in any of these matters amounts to hardly more than political camouflage.
- Using global averages for the parameters will tend to ameliorate drastic implications of uninhibited growth, thereby averting possible criticism of having exaggerated the consequences. In reality, localized parameters are much more meaningful for assessments which address limitations imposed by climatic effects, finite energy and land resources and economic constraints.

CLIMATIC LIMITS

Most of the energy utilized (except for a relatively small amount that is converted to long-term storage such as in pumped lakes or in durable products manufactured via endothermic processes) is converted within a short time span into terrestial heat which eventually must be radiated into outer space. Since earth-atmosphere is in radiative equilibrium with the sun, all energy released from long term storage by man's activities (anthropogenic) such as in burning fossil fuels can be rejected to outer space only if the equivalent blackbody temperature of the earth-atmosphere system increases, assuming that the emissive and reflectance characteristics remain essentially constant (which for present purposes is a tenable assumption).

The energy transactions between the sun and the earth-atmosphere are governed by the generalized accountability principle (First Law of Thermodynamics):

$$\textit{Input} - \textit{Output} = \textit{Accumulation} \qquad (3)$$

which is equally applicable to financial and population balances. For the specific case here, Equation 3 can be expressed as

$$(\dot{q}_s) - (\dot{q}_r + \dot{q}_e) = \dot{E}_N \qquad (4)$$

where $\dot{q}_s$ is the incoming solar flux to the top of the earth-atmosphere, $\dot{q}_r$ and $\dot{q}_e$ are the reflected and emitted energy fluxes, respectively, from the earth-atmosphere and $\dot{E}_N$ is the accumulated or net energy flux. All fluxes are expressed in Btu/hr-ft².

For radiative equilibrium, $\dot{E}_N = 0$. Also, by definition $\dot{q}_r/\dot{q}_s = \omega =$ the albedo or the reflectivity of the earth-atmosphere system. Furthermore, according to the Stefan-Boltzmann equation, $\dot{q}_e = \sigma\varepsilon T_e{}^4$. Thus, Equation 4 becomes

$$T_e = \left[\frac{1-\omega}{\sigma\varepsilon}\ (\dot{q}_s)\right]^{1/4} \qquad (5)$$

where T_e is the absolute temperature of the earth-atmosphere system, σ is the Stefan-Boltzman constant and ε is the emissivity of the earth-atmosphere system.

Since we are interested in global averages, ω is set equal to 0.33 (for the intended use, a more precise figure is inconsequential) and T_e and $\dot{q}_s$ become $(T_e)_{avg}$ and $(\dot{q}_s)_{avg}$. Based on extensive satellite measurements, which confirmed earlier predictions, the solar constant, $\dot{q}_s$, is 428.9 Btu/hr-ft². Since $\dot{q}_s$ is the incoming solar flux impinging on the earth's diametral plane perpendicular to the sun, then

$$\dot{q}_s\ (\pi r^2) = (\dot{q}_s)_{avg}\,(4\pi r^2) \qquad (6a)$$

so that

$$(q_s)_{avg} = \frac{\dot{q}_s}{4} = \frac{428.9}{4} = 107.2\ \text{Btu/hr-ft}^2 \qquad (6b)$$

where $(\dot{q}_s)_{avg}$ represents the average incoming solar flux distributed over the entire surface of the earth-atmosphere system. By setting the emissivity (ε) equal to one, the temperature $(T_e)_{avg}$ becomes the equivalent blackbody temperature which is sufficient for present purposes since our principal interest will be in temperature differences rather than absolute magnitude. Also, $\sigma = 0.173 \times 10^{-8}$ Btu/hr-ft² — $(^\circ R)^4$. Equation 5 thus becomes

$$(T_e)_{avg} = 100\ [3.873\ (\dot{q}_s)_{avg}]^{1/4} \qquad (7)$$

The anthropogenic energy, which represents the additional radiative heat burden and forces the temperature to rise, can be expressed in terms of fractional equivalents of $(\dot{q}_s)_{avg}$ and is denoted by "f". The temperature rise due to anthropogenic energy is:

$$(\Delta T) = 100\,[3.873\,(1+f)\,(\dot{q}_s)_{avg}]^{1/4} - 100\,[3.873\,(\dot{q}_s)_{avg}]^{1/4} \qquad (8)$$

Combining with Equation 6,

$$\Delta T = 451.4\ [1+f)^{1/4} - 1] = {}^\circ R = {}^\circ F \qquad (9)$$

The area of the earth's surface (land and water) is approximately 5.5 x 10^{15} ft^2; thus, the total amount of solar energy reaching the earth's atmosphere is 5.17 x 10^{21} Btu/yr based on $(q_s)_{avg}$ = 107.2 Btu/yr. Since the world's energy consumption for 1975 is estimated at 2.42 x 10^{17} Btu, f= 4.7 x 10^{-5} which is sufficient to raise the temperature of the earth-atmosphere only 0.005°F. This magnitude cannot be detected since over the past century, for which information is available, the earth's mean temperature has fluctuated about ±1°F, presumably due to variations in sunspot activity. In addition, the estimated temperature fluctuations resulting from aerosols released to the atmosphere are on the order of another ±1°F, so that in the worst case where these two types of fluctuations could by chance reinforce each other, ±2°F, temperature increases of less than 2°F due to anthropogenic energy could not be determined with any degree of reliability. However, over some localized areas, such as Manhattan and Moscow, the anthropogenic energy exceeds by several multiples the incoming flux, and "permanent" temperature increases have been confirmed locally. Fortunately for these areas, the localized heat generated is, for the most part, diffused over a wide surrounding area where anthropogenic energy fluxes are still quite insignificant. The inescapable evidence is that as our energy demand continues to escalate, we can anticipate temperature increases leading to climatic repercussions.

A series of calculations were made by holding r constant and letting n vary in Equation 1 and letting f vary in Equation 9. The results are summarized compactly in Fig. 2, based on the 5 percent per annum growth rate which has prevailed over the past century with no tangible indications, as yet, of abating. The predicted temperature increases shown on the left-hand ordinate are probably conservative; in fact, they could be low by a factor of 2 or 3, insofar as climatic impact is concerned. The use of global average, which assumes that all the heat generated in a localized area is immediately diffused uniformly over the entire earth, is quite unrealistic. Before this gentle averaging process could transpire, major upheavals in the earth's climatic processes could occur. Without elaborating, there are additional factors that could aggrevate the temperature rise problems.

The underlying assumption of a 5 percent annual growth in demand for each class of fuels (Fig. 2) must be emphasized. Obviously, if the annual demand for a particular fuel decreases, the demand for another fuel must increase in order to maintain the overall 5 percent per annum rate. So long as solar energy does not command a major share of the energy market, the climatic effect will correspond to Fig. 2, on which several benchmarks have been identified as being of particular significance.

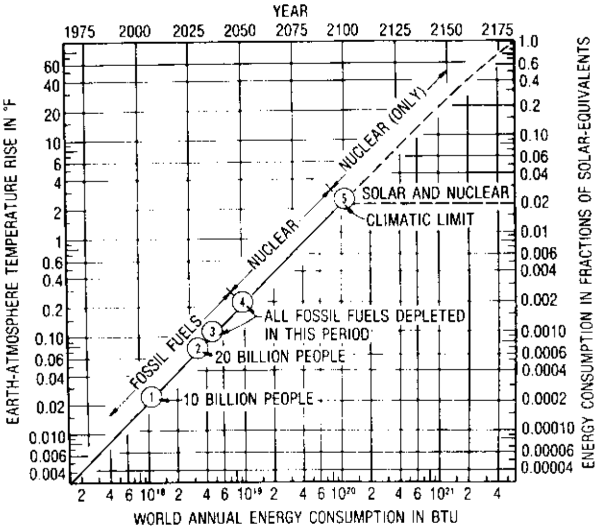


Fig. 2—Potential consequences of world energy growth at 5 percent per annum.

Benchmark ① represents the year 2005 in which the projected population of the Earth will reach 10 billion if a growth rate in population of 3 percent per annum is maintained. At this point, the world's per capita consumption of energy would increase from the present 16 percent to 28 percent of 1975 per capita energy consumption in the United States. Benchmark ② represents the year 2029 when the world's population would reach 20 billion based on the 3 percent per annum growth rate. At this point, the world's per capita consumption of energy would be about 44 percent of 1975 figure for the United States. The significance of these two population levels will be explained later, but one other point merits comment. These benchmarks are based on a 5 percent per annum growth in total energy. Since the population is growing at about a 3 percent rate, then it would appear that the indicated consumption in energy per capita is growing at an annual rate of 1.94 percent. However, over the past decade the world energy per capita consumption has been growing at a rate of 3.2 percent which, when combined with a 3 percent growth rate in population, would predict an annual increase in total energy consumption of 6.3 percent. On this basis the annual energy consumptions in 2005 would be 50 percent greater and in 2029, 100 percent greater, than are indicated in Fig. 2 by Benchmarks ① and ②.

Benchmarks ③ and ④, corresponding to the years 2038 and 2052, respectively, bracket the time interval when all of the world's reserves of petroleum, gas, coal, oil shale and tar sands would be depleted assuming that the contributions from other sources, such as nuclear, did not decrease the annual growth in demand for fossil fuels. Life expectancies of 63 or 77 years for fossil fuel reserves computed from Equation 2, assume that total reserves lie somewhere between 1 x 10^{20} and 2 x 10^{20} Btu; estimates which may be optimistic in terms of ultimate recoveries. These reserves would last 413 years and 826 years, respectively, if 1975 consumption rates prevailed throughout the time periods, which would entail no further increases in annual fossil fuel consumption from this day forward. To prolong the life of our fossil fuels, which also constitute the best feedstock for petrochemicals and a potential source for protein, other forms of

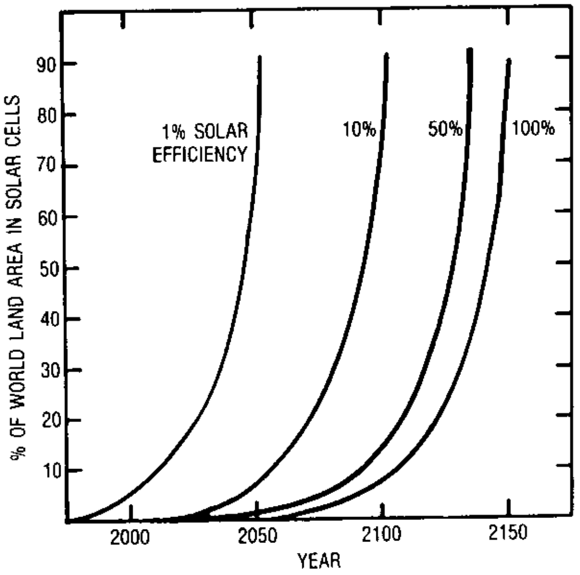


Fig. 3—Effect of solar cell efficiency on land area requirements to supply world energy growth at 5 percent per annum.

energy, such as nuclear, solar and geothermal, would have to satisfy all of the annual growth in energy demand and preferably much more.

If energy consumption continued to grow at 5 percent per annum, presumably by utilization of nuclear energy or any other forms of energy which can be released from long term storage, eventually Benchmark ⑤ will be reached. This benchmark identifies a climatic limit for allowable temperature rise in earth-atmosphere. Climatologists who have studied this problem generally agree that when anthropogenic energy reaches about one or two percent of solar flux, climatic consequences become a matter of concern. Thus, Benchmark ⑤ (Fig. 2) is located at 2 percent, corresponding to a temperature rise of about 2.2°F, which is slightly greater than temperature fluctuations of ±2°F discussed above. Accordingly, climatic limit would be reached in the year 2100. Note that if the climatic limit had been taken to be 20 percent, instead of 2 percent, the cutoff year would have been in 2146, an extension of only 46 years.

Between Benchmark ④ and ⑤ nuclear, solar and geothermal (where available) energy would have to become primary sources if our fossil fuel reserves were depleted. Beyond Benchmark ⑤, if the 5 percent energy growth rate persisted, direct conversion of solar energy would have to provide all of the energy demands in excess of 2 percent of the solar flux or, equivalently, 10^{20} Btu/yr in order to avoid exceeding the climatic limit. Solar power, theoretically, could continue to supply the 5 percent growth demand until about the year 2175 when the demand rises to 5 x 10^{21} Btu/yr, which would require converting 100 percent of the solar flux reaching the top of the earth's atmosphere into man's needs, an unrealistic wish, as will be seen later.

TABLE 1—Windfall?

- Strip mine coal in Wyoming containing 100,000 tons/acre (2,500 x 10^9 Btu/acre)
- Reclaim land and plant
  - Slash Pine (0.25 percent soalr efficiency) 40,000 years to "grow" 2,500 x 10^9 Btu
  - Corn (1 percent solar efficiency) 12,000 years to "grow" 2,500 x 10^9 Btu
- During 1975 in the U.S., 2,500 x 10^9 Btu's of energy are being consumed every 16 minutes and 2,500 x 10^9 Btu's of coal are being burned every 80 minutes.

To summarize, man has the energy resources at his disposal now to sustain a 5 percent per annum growth in energy demand over the next century or two. So long as he has, incentives will be lacking for him to curb his insatiable appetite for energy until passive factors intervene.

OPTIONS FROM DEPLETABLE RESOURCES

World reserves of petroleum and natural gas are in most imminent danger of becoming depleted. Their closest relatives, tar sands and oil shales, are prevalent in amounts comparable to combined reserves of petroleum and natural gas, but ultimate recoverabilities still remain a major question. Of all fossil fuels, coal is by far the most abundant since it comprises more than 80 percent of the total. Aside from much-publicized problems associated with its extraction and utilization, coal offers the most prominent, near-term relief for our dwindling petroleum and natural gas supplies.

Part of this controversy over coal can be attributed to misconceptions. For example, one of the most exhortative advertisements for opening up the western coal lands reads: *"27 acres of land near Gillette, Wyo., can almost feed one steer for one year or these same acres will yield enough coal to generate the electric living needs of over one million people for one year."*

Ostensibly, this outcome represents a profitable trade-off. However, what this advertisement fails to mention is that it is virtually a one-time windfall since it would take (Table 1) more than 10,000 years to replenish this strip-mined land with equivalent energy which, in terms of today's consumption rates, would satisfy our energy needs for only a matter of minutes. (It should be pointed out here that the Gillette location represents an unusually rich coal seam, by a factor of 10 or 20 over most coal stripping operations.) One other possibility is that by reclaiming the strip-mined land for agriculture, it could be used to feed about five steers per 27 acres, rather than the original one. Again, this trade-off has its merits, but unfortunately in this particular area where the rainfall is about 10 to 15 inches per year and where the soil does not have adequate moisture retention, reclamation for agriculture is not too promising. Therefore, *we must recognize the trade-offs and decide on the compromises for "we can't have our cake and eat it, too."*

Unquestionably, nuclear energy represents by far our largest depletable energy reserve if we include breeder (fission) and fusion reactors. Controversy surrounding its utilization is primarily one of safety, which probably will become a matter of diminishing concern in the years ahead, not necessarily because of technological breakthroughs on safeguards but because of the impending exhaustion of our fossil reserves. In other words, there is a likely probability that the public will passively accept greater risks rather than decrease their demand for more energy—particularly in those areas where other options are not available. Nuclear energy enjoys the advantage of requiring the least amount of transposition.

Although geothermal energy is frequently cataloged with solar sources, it is more akin to fossil and nuclear fuels in that it is depletable and its utilization results in the sudden release of energy which has been in long term storage. Therefore, its climatic impact is identical to that of fossil and nuclear fuels. In addition, it is not yet clear whether the removal of large quantities of thermal energy from beneath the earth's surfaces resulting ultimately in abnormal, localized temperature gradients, could trigger some yet-to-be identified, sub-surface instabilities. Perhaps we need an analysis similar to Fig. 2 but concerned instead with temperature decreases in the ground.

Notwithstanding, geothermal energy can make an environmentally acceptable and substantial contribution in particular areas. Although the geothermal reserves in terms of sub-surface steam or hot water are only a fraction of a percent of the fossil fuel reserves, the potential in hot dry rock is substantial, conceivably two orders of magnitude larger than our fossil fuel reserves. The utilization of hot dry rock involves drilling two or more wells into the rock, which is fractured hydraulically so that wells are connected. Pressurized cold water is then injected down one well into the rock where it is heated. It then rises to the surface through a second well, thus creating an "artificial" geothermal system. Proposed depth of these wells, up to seven miles, is within capability of existing petroleum and natural gas drilling practice. Major technology that remains to be developed is fracturing of granitic rocks at these depths. This task appears to be substantially less onerous than development of controlled fusion reactors. All things considered, geothermal energy could contribute significantly to preserving our fossil fuels and relieving some of the pressures for expanding nuclear utilization.

POTENTIAL OF RENEWABLE RESOURCES

Although total amount of solar energy reaching earth's atmosphere is 5.17×10^{21} Btu/yr (25,000 times our current annual energy consumption), its average flux over the earth's surface is only around 107 Btu/hr-ft.^{2} An individual occupying a circle 2 feet in diameter emits more "body-heat" (assuming all of it could be directed downward onto the circle) than sun shining on the same area. At the other extreme, fluxes of over 200,000 Btu/hr-ft^2—2,000 times greater than the solar flux—are encountered in industrial practice. It therefore follows that solar collectors will require an inordinately large amount of real estate as indicated by Fig. 3. Over the next 50 years, the land area requirements are not particularly onerous, even at 1 percent efficiency, but as the 5 percent per annum growth in demand continues, solar collectors for the long pull become less and less attractive, regardless of efficiencies.

TABLE 2—Longevity of finite resources

Resource	Estimated world reserves in Btu	Years of supply or to cutoff, assuming 100% recoveries	
		Based on current annual demand 2.42×10^{17} Btu	Based on 5% per annum growth rate
Fossil fuels	2×10^{20}	800	75
Geothermal (including hot dry rock)	2×10^{22}	80,000	180
Nuclear (including all deuterium in ocean)	5×10^{27}	2×10^{10}	(125-425)*
Solar**	5×10^{30}	2×10^{13}	(200-525)**

* Although total supply of energy from all nuclear sources (fission and fusion) is sufficient for 400 years, "climatic limit" will restrict its utilization after the year 2100 to about 10^{20} Btu/year in which case its supply would last about 50 million years.

** Estimates indicate that the sun can last another billion years based on assuming a 1 percent conversion for its fusion reaction. Since the sun delivers 5×10^{21} Btu's per year to the Earth, sun reserves are $(5 \times 10^{21})(10^9) = 5 \times 10^{30}$. Absolute maximum annual utilization of sun's energy (assuming 100 percent recoveries) appears to be limited "forever" to 5×10^{21} Btu's; therefore, sun cannot support any further growth in energy demand beyond the year 2175. Total energy of sun available to earth as represented by 5×10^{30} Btu's corresponds to a life of about 525 years at 5 percent per annum.

One could argue that solar collectors could be deployed over the oceans, thereby releasing land space. Aside from the obvious difficulties and losses associated with transferring the converted solar energy back to the land, one would be concentrating the incoming solar radiation over the water onto the land—like a giant magnifying glass—and aggravating the local heat rejection problems discussed above, not to mention the impact on the oceans. Orbiting solar collectors would not offer any relief since they require about 40 percent more land area for the receivers than equivalent land-based collectors. For the same power output, these receivers require 6 times the area of a coal-burning power plant and 20 times the area for a nuclear plant.

Despite these shortcomings, solar energy will be used in heating residential and commercial buildings, particularly where the collectors can be mounted on rooftops and vertical walls so as to minimize the amount of extra land area required for this purpose. This application can relieve about 20 percent of the total energy market, which helps but is not the total answer to the energy problem.

Another prospect for solar energy conversion is so-called "green machine" which harvests photosynthesis for fuel production. Since wood was our first source of fuel (its current contribution to total energy market is still greater than nuclear energy), green machine is a rejuvenation of a former way of life. Its staunchest advocates argue that it does not give off noxious fumes; it gives off oxygen. The same argument holds for all fossil fuels during their original process of formation. But, burning "Btu bushes" is no different from burning fossil fuels. Another argument for green machine is that it constitutes a renewable resource. Again, one cannot take issue with this statement, per se, but it needs to be evaluated carefully. Btu bushes are solar collectors and relatively poor ones at that. Conversion efficiencies on the order of 1 percent are presently attainable with hopes that they can be increased eventually to 5 or 10 percent. Fig. 3 tells the rest of the story; before long, at a 5 percent growth rate in energy demand, we would run out of land area.

Indirect forms of solar energy, such as can be derived from the wind, stream-flow, ocean tides and ocean temperature gradients should not be ignored; but in the long term, if current growth rate in energy demand persists, potential contributions from these sources would be insignificant. Nevertheless, since it is the 5 percent growth rate that is creating the problem, any contributions from these sources that could shave even a fraction of a percent from this escalating burden on fossil reserves should be pursued.

In summary, then, comforts that we can expect to

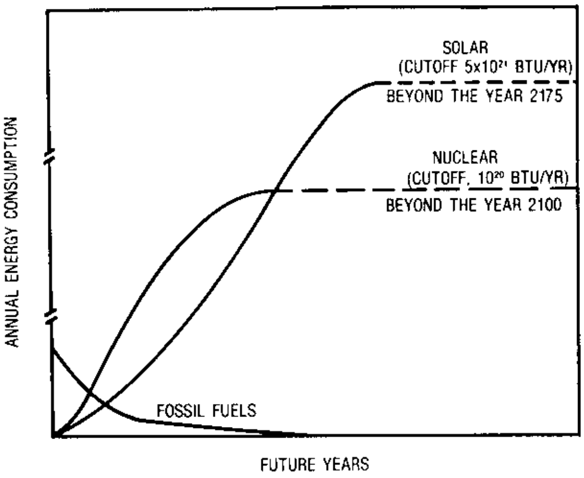


Fig. 4—Required trends in energy derivatives to sustain a 5 percent per annum growth over the next two centuries.

derive from that ultimate resource, the sun, are not all that bright; in some respects, prospects are somewhat bleak compared to what has been publicized.

FINITENESS OF ALL RESOURCES

Although to date we have consumed only a 0.5 percent (or thereabouts) of our initial reserves of fossil fuels, we are on the threshold of exhausting them well within the next century if 5 percent per annum growth rate persists. The question now arises whether so-called inexhaustible resources—nuclear and solar—are really limited. Table 2 provides estimates. Basically, due to climatic limit, potential from nuclear energy will be limited to 10^{20} Btu/yr beginning with the year 2100. Shortly thereafter, in 2175, rate at which the sun delivers energy to the earth's top atmosphere, 5 x 10^{21} Btu/yr, would be reached. Since these projections do not take into proper account efficiencies of utilization, they are optimistic.

To sustain 5 percent growth rate, nuclear, solar and geothermal sources will have to begin absorbing a significant portion of total energy demand before turn of the century and will have to escalate at an ever-increasing rate thereafter. This growth could continue until nuclear and geothermal reach climatic limit in about 2100 and solar energy reaches solar flux limit in about 2175. Beyond this point annual energy demand could not increase. A qualitative indicator of the relative shifts that would have to take place in our energy sources to sustain the 5 percent growth rate is shown in Fig. 4. At lower annual growth rates, these curves would be stretched out along the time axis.

POPULATION CONSTRAINTS

Thus far, man has demonstrated little inclination to arrest his growing demands for energy. However, there are other constraints which can bring him to a realization that he must alter his ways.

Currently world population which is around 4 billion has been growing at 2 to 3 percent per annum. Like energy per capita, a certain minimum amount of land is required to sustain each individual. In 1970, availabile land per capita was distributed across the earth as shown in Table 3, but these allotments have been changing rapidly due to the exponential growth in population. Estimates of the maximum population that could be supported on a diet of 12,000 Btu per day per capita indicate about 10 billion, which would be reached around the year 2005 based on a 3 percent growth rate. (Current world average is around 8,000 Btu per day per capita with about half of the world's population grossly underfed for productive activity.) Of the 36.7 billion acres comprising the total land area, 8 billion acres are potentially arable and another 8 billion acres qualify for grazing. Thus, with 10 billion people, only 1.6 acres, or about 70,000 ft^2, of agricultural land would be available for each person. Benchmark ① (Fig. 2) was selected to correspond to the year in which the population would reach 10 billion; since if it were frozen at this level, it would constitute the first, external deterrent to escalating energy demands.

Others have speculated on the possibility of supporting 20 billion people. In fact, some nuclear enthusiasts boast that they are ready, willing and able to provide energy for 20 billion people at an average per capita for four times current U.S. per capita consumption. Benchmark ② corresponds to this population level but at an energy per capita of about 44 percent of the current U.S. rate.

In the matter of assuring adequate food supplies, we cannot afford to rely too much on speculations as to

TABLE 3—Reciprocal population density in 1970

Region	Acres per capita	Comments
Oceania	108.	
S. America	23.2	
U.S.S.R.	22.8	
Africa	21.7	
N. America	18.7	
	←	U. S. = 11.3
	←	World = 9.23
Asia	3.31	
Europe	2.64	

TABLE 4—Decrease in land area[a] per capita due to population increases

Year	World ft^2/capita at 3% annum	Comparisons with present quantities	U.S. ft^2/capita at 1.5% annum
1975	394,000		463,000
2000	188,000		319,000
	(b)	W. Europe = 115,000	
2025	89,900		220,000
	(c)	India = 62,000	
2050	42,900		152,000
	(d)	Netherlands = 33,000	
		or	(e)
		Japan = 38,000	
2075	20,500		104,000
2100	9,790		72,000
			(f)
			(g)

(a) Land area of earth = 1.6 x 10^{15} ft^2; of U.S. = 1 x 10^{14} ft^2.
(b) Corresponds to a world population of about 14 billion.
(c) Corresponds to a world population of about 26 billion.
(d) Corresponds to a world population of about 45 billion.
(e) Corresponds to a U.S. population of about 0.9 billion.
(f) Corresponds to a U.S. population of about 1.6 billion.
(g) Corresponds to a U.S. population of about 2.8 billion.

what might be done to increase food supply; rather, we should base such projections on what has already been accomplished and accept any "bonanzas" as a compassionate reward. Therefore, based on this conservative outlook, is there an upper limit on population? Table 4 gives some presumptive indications. Western Europe farms its available land much more intensively than the United States; it produces about 50 percent more calories of food per acre than the United States does. (There are parts of Europe that also suffer from inadequate diets.) Therefore, based on the European style of agriculture, conceivably 14 billion people could survive on this Earth. Japan produces about three times as many calories per acre as the United States. Assuming that the world could become as resourceful as Japan and that it could survive on the Japanese diet, then possibly 24 billion people could be accommodated.

Undoubtedly the most startling estimate for ultimate limit on world's population comes from a truly eminent biologist who holds that "the limit is when there are enough people that the people-generated heat boils the waters of the ocean." Without going into details, assuming that all people-generated heat is captured and retained by oceans—it would take 10^{15} (one million billion) people 100 years to bring oceans just up to boiling without vaporization taking place. This population level translates into 1.6 ft^2 of land area for each person.

Aside from reserving enough land for food production, one should not depreciate need for just plain "elbowroom" in a psycho-social sense. True, Japanese and Dutch have become accustomed to a high population density, but they had literally centuries over which to make gradual adjustment. Could others make a comparable adjustment for an increase in population density by a factor of 10 within the next 50 years? Obviously, there are many other elements involved in population growth such as availability of water supplies, provisions for waste disposal, elimination of potential hazards and concomitant increased energy and capital requirements which have to be included. When these factors are taken into consideration, a more rational estimate of an upper limit for population—to which many authorities subscribe—seems to be somewhere around 8 billion which will be reached in 1997 if a 3 percent growth rate prevails (only eight years away from the 10 billion figure).

ECONOMIC FACTORS

We are repeatedly warned that unless we continue to feed escalating demands for energy, a precipitous, economic collapse will occur world-wide. The most pervasive argument for this hypothesis has been alleged linear relationship between gross national product (GNP) per capita for a given country and commercial energy consumption per capita.

Until the 1970s, the United States had highest GNP per capita—about 50 percent greater than its nearest competitor, Canada, and double that of Western Europe. This observation apparently led to the conclusion that a high GNP per capita was equivalent to a high standard of living and that the GNP per capita constituted "the most basic measures" of economic health or the level of industrial development. Yet, in 1974 Kuwait had a GNP per capita 1.7 times greater than the United States, 4.2 times higher than its neighbor, Saudi Arabia, and 8.6 times higher than "modern" Iran. (Switzerland, Sweden and Denmark also had higher GNPs per capita than the United States during 1974.) Even before these sudden surges in inflation and growth during the 1970s, it was suspected that GNP per capita might be less of a fundamental economic parameter (other than a measure of waste and extravagance in the use of physical resources) and more of a statistician's delight.

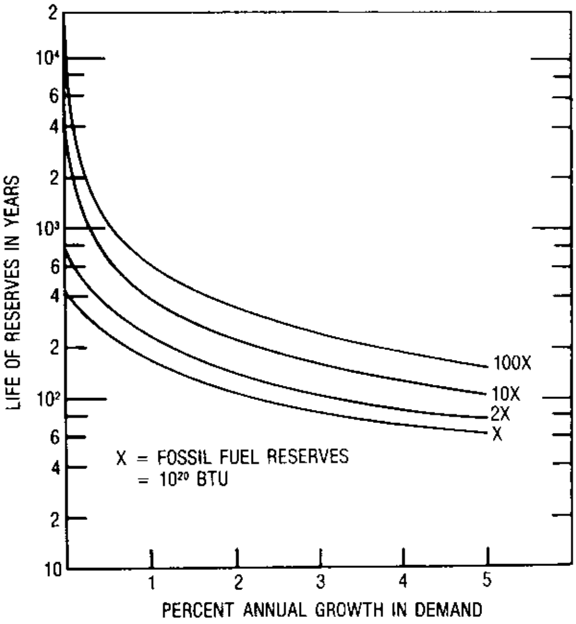


Fig. 5—Effect of annual growth rate and magnitude of reserves on life span for fossil fuels.

A high per capita energy consumption has been touted as a prerequisite for high output of goods and services. If so, then it is difficult to explain why prior to 1970 (before the inflationary growth explosion) France had the same GNP per capita as the United Kingdom but consumed less than ½ as much commercial energy per capita; while Japan, with the same GNP per capita as Poland, required ⅓ as much energy per capita, etc.

Finally, ratio of commercial energy to GNP is supposed to be indicative of the standard of living. If so, then why—at least up to 1970—did India, Brazil and Spain have the same ratio of energy to GNP as the United States and the Netherlands?

Returning to the argument for growth, it should be pointed out that a number of respected, free-world economists, who are proponents of capitalistic enterprise, have been contending that growth is not a prerequisite for a viable economy. Obviously, they will have to speak louder in order to be heard.

Notwithstanding polemics of these two opposing schools of thought, there seems to be ample evidence that we cannot tolerate physical growth much longer. We should become more concerned with a fractional percent increase in energy growth than we presently are in prime interest rates. The latter is measured in dollars which are inflatable, whereas Btu's are not. Shutting-off the growth valve instantaneously would undoubtedly result in severe economic repercussions. Perforce, however, we must learn posthaste how to apply the brakes gradually, but positively and just short of skidding.

CLOSURE

We have acquired a self-defeating penchant for consuming energy at a faster rate (5 percent per annum) than population growth rate (2-3 percent per annum). Although in the 1950s and 1960s, increase in food supply did not keep up with population surge, recent indications are that food supply may now be ahead of population, but just barely. However, this reversal offers little basis for elation since about half of the world's population is still at brink of starvation and is particularly vulnerable to a crop failure since food reserves are dangerously low. Emerging then are two horns of a dilemma: mass starvation or mass genocide. Who will judge which is less inhuman?

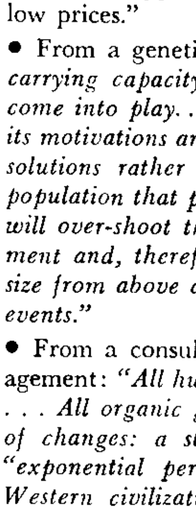
To be sure, we shall continue to debate alternatives for resolving our energy predicament before we take concrete action. A major reason for this state of delinquency is confusion arising from conflicting viewpoints, as indicated by the following examples:

- From an executive in energy production: *"We firmly believe the safest course for the United States will be to encourage the development of additional energy supplies while continuing the national dialogue with respect to the desirable level of consumption."* He supports his case for increased supplies so that "we will have energy surplus at low prices."
- From a geneticist: *"The factor which most limits the carrying capacity of the environment is the last one to come into play. . . .As the affluence of a society increases, its motivations are more and more governed by short-term solutions rather than long term considerations. . . . Any population that primarily responds to short-term problems will over-shoot the true carrying capacity of its environment and, therefore, will approach its eventual limiting size from above as the result of one or more catastrophic events."*
- From a consultant in creativity, innovation and management: *"All human behavior is oriented toward growth. . . . All organic growth goes through a natural sequence of changes: a slow "linear" beginning, an accelerated "exponential period" and a decelerated linear period. Western civilization is merely going through a natural stage of growth which will evolve into the final mature stage, when psycho-social growth will largely replace physical growth. Natural growth process regularly generates crisis and just as naturally, through evolution, meets the challenge. Expecting the future to work just like the past, with continuing exponential growth, is unorganic, unnatural and false."*

Regardless of personal viewpoints, one inescapable fact is that we cannot tolerate a 5 percent per annum increase in energy consumption regardless of the magnitude of energy reserves. For example, increasing our reserves of fossil fuels by a factor of 100 increases life span from 63 to 150 years at the 5 percent annual rate (Fig. 5). We need to decrease our annual growth rate well below 1 percent before the magnitude of reserves has a substantial impact on their life span. Putting it another way, if through a combination of conservation and efficiency of utilization we could reduce our annual consumption of fossil fuels by a factor of 2, we could only extend their life span by one doubling period, or less than 15 years, if our annual demand continued to grow at the 5 percent rate.

On the other hand, by moving expeditiously toward zero growth in energy and population, we would simultaneously relieve burdens on all of our natural resources and climatic effects. Granted, such exhortations are easier suggested than accomplished; nevertheless, the difficulty of the task is not justification for inaction. Without making any allowances for the greatest obstacle of all, bureaucratic ineptitude, if we make a positive commitment now to the deceptively simple, but excruciating, concept of zero growth in energy and population, it will still take probably 50 years or more to stabilize at a propitious level. Until we have some other concrete evidence, we cannot afford to gamble that the problem will take care of itself through natural, benevolent self-adaptation without any help from man. The penalty for guessing wrong would be irreparable.

About the author



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