World Energy Production, Population Growth, And the Road to the Olduvai Gorge

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The Olduvai theory is defined by the ratio of world energy production and population. It states that the life expectancy of Industrial Civilization is less than or equal to 100 years: 1930-2030. After more than a century of strong growth — energy production per capita peaked in 1979. The Olduvai theory explains the 1979 peak and the subsequent decline. Moreover, it says that energy production per capita will fall to its 1930 value by 2030, thus giving Industrial Civilization a lifetime of less than or equal to 100 years. This analysis predicts that the collapse will be strongly correlated with an 'epidemic' of permanent blackouts of high-voltage electric power networks — worldwide.

KEY WORDS: Olduvai theory; energy; population; industrial civilization; overshoot; electricity; collapse.

This subject was presented to the Pardee Keynote Symposia, Geological Society of America, Summit 2000 in Reno, Nevada on November 13, 2000 — more than two months before the rolling blackouts of electricity began in California.

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> Collapse, if and when it comes again, will this time be global. No longer can any individual nation collapse. World civilization will disintegrate as a whole. Competitors who evolve as peers collapse in like manner. — Joseph A. Tainter, 1988

INTRODUCTION

The Olduvai theory has been called unthinkable, preposterous, absurd, dangerous, self-fulfilling, and self-defeating. I offer it, however, as an inductive theory based on world energy and population data and on what I've seen during the past 30 years in some 50 nations on all continents except Antarctica. It is also based on my experience in electrical engineering, my interests in anthropology and archaeology, and a lifetime of reading in various fields.

The Olduvai theory is a data-based schema that states that the life expectancy of Industrial Civilization is less than or equal to 100 years. We shall develop the theory from its early roots in Greek philosophy down to respected scientists in the 20th century. This time-line approach is important because (1) the theory has a long and distinguished history, and (2) although it is easy to understand, it is difficult (i.e. distressing) for most people to accept — just as it was for me.

The Olduvai Gorge is a gentle picturesque valley that extends east to west within the Serengeti National Park in northern Tanzania. The Olduvai theory, however, deals neither with the layered geology or the famous paleontology of the Olduvai Gorge. Nor is it prescriptive. Rather, the theory simply attempts to explain the historic world energy production (and use) and population data in terms of overshoot and collapse. I chose the name "Olduvai" because (1) it is famous for the myriad hominid fossils and stone tools discovered there, (2) I've been there, (3) its long hollow sound is eerie and ominous, and (4) it is a good metaphor for the 'Stone Age way of life.' In fact, the

Olduvai way of life was (and still is) a sustainable way of life — local, tribal, and solar — and, for better or worse, our ancestors practiced it for millions of years.

No doubt that the peak and decline of Industrial Civilization, should it occur, will be due to a complex matrix of causes, such as overpopulation, the depletion of nonrenewable resources, environmental damage, pollution, soil erosion, global warming, newly emerging diseases, and resource wars. That said, the Olduvai theory uses a single metric only, as defined by "White's Law." *But now I foresee a calamitous "trigger event" — the declining reliability of electric power grids.*

The Olduvai theory, of course, may be proved wrong. But at the present time, it cannot be rejected by the historic world energy production and population data.

Most of my industrial experience is in electric power networks and the energy management systems (EMS) that control them. Electricity is not a primary energy source, but rather an "energy carrier": zero mass, travels near the speed of light, and, for all practical purposes, it can't be stored in significant quantity. Moreover, electric power systems are costly, complex, voracious of fuel, polluting, and require 24h-7d-52w operations and maintenance. Another problem is that electricity is taken for granted. Just flip the switch and things happen. In short: Electricity is the quintessence of the 'modern way of life,' but the electric power systems themselves are demanding, dangerous, delicate, and vulnerable. All this suggests that permanent blackouts will be strongly correlated with the collapse of Industrial Civilization — the so-named 'Olduvai cliff,' discussed later.

The original discussion of these ideas was presented at the 2000 annual meeting of the Geological Society of America, and was accompanied by a slide show titled "The Olduvai Theory: An Illustrated Guide" (see Duncan, 2000c). This paper, however, contains the full discussion and technical details of my GSA presentation.

Definitions

‘Oil’ (O) means crude oil and natural gas liquids. 'Energy' (E) means the *primary* sources of energy — specifically crude oil, natural gas, coal, and nuclear and hydroelectric power. 'Pop' means world population. 'ô' means oil production per capita. 'ê' means energy production per capita. ‘G’ means billion (10^9). ‘b’ means barrels of oil. 'boe' means barrels of oil equivalent (energy content, not quality). 'J' means joule. 'C^3' refers to the three cybernetic functions: communication, computation, and control. 'Industrial Civilization' and 'Electrical Civilization', as we shall see, mean the same thing.

Industrial Civilization is shown as a pulse-shaped curve of world average energy-use per capita (ê). The 'life expectancy' (i.e. 'duration') of Industrial Civilization is defined as the time (in years) between the upside point when ê reaches 30% of its peak value and the corresponding downside point when ê falls to the same value (Figure 4). The new twist is that the Olduvai theory now focuses on the mounting problems with the high-voltage electric power networks — worldwide.

Civilization and Ready Kilowatt

Although the fossil fuels are still very important, electricity is the indispensable *end-use* energy for Industrial Civilization. To determine its importance, it is essential to distinguish between the primary energy 'consumed' to generate electricity *versus* the primary energy consumed for all other (i.e. non-electric) end-uses, such as transportation and space heating. Consider the following. I estimate that 42% of the world's primary energy in 1999 was consumed to generate electricity. This compares to oil's contribution to all non-electric end-uses of 39%; natural gas' contribution of 18%; and coal's contribution of a mere 1%. Moreover: When *energy quality* is accounted for, then the importance of electricity becomes very, VERY clear. For example, if you want to heat your room, then 1 joule (J) of natural gas is 'equal' to 1 J of electricity. However, if you want to power up your computer, then 1 J of electricity is 'equal' to 3 J of natural gas! Further, without the crucial C^3 functions — communication, computation, and control — Industrial Civilization itself is crippled. So if you're going to worry about energy, then don't lose sleep over oil, gas, and coal. *Worry about the electric switch on the wall!*

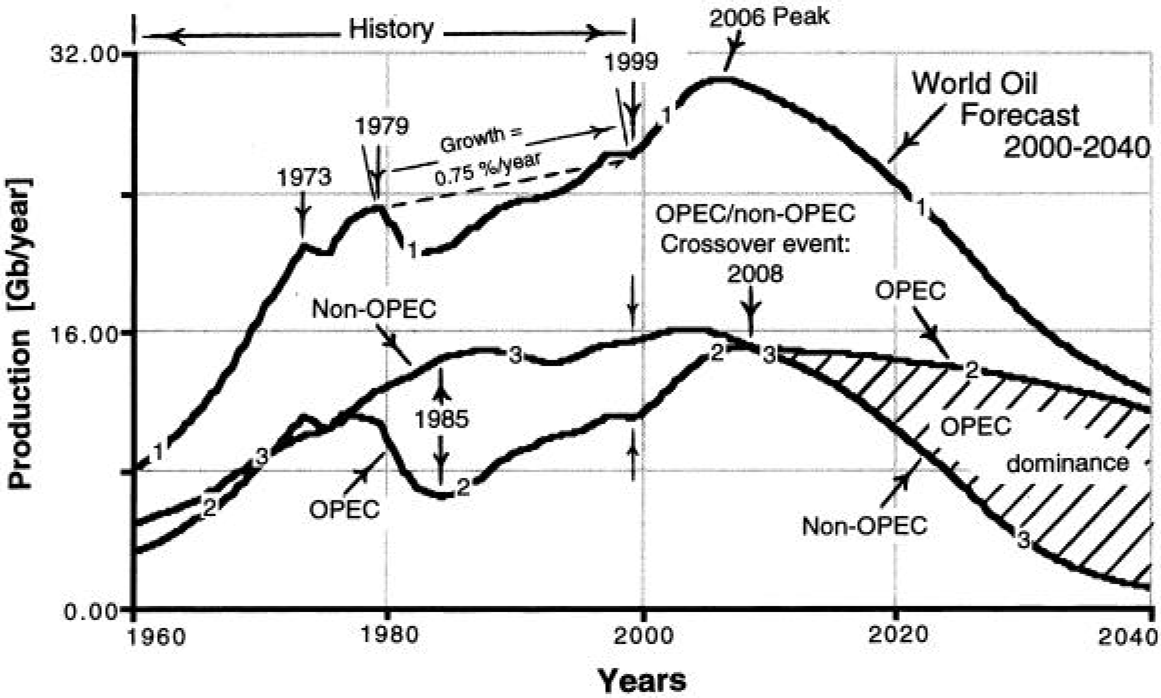
ENERGY AND CIVILIZATION

> Other factors remaining constant, culture evolves as the amount of energy harnessed per capita per year is increased, or as the efficiency of the instrumental means of putting the energy to work is increased. … We may now sketch the history of cultural development from this standpoint. — Leslie White, "White's Law," 1949

Oil, natural gas and coal in 1999 accounted for 89.8 % of the world's primary energy consumption, and nuclear and hydropower for 10.2 % as follows: oil 40.6 %, gas 24.2 %, coal 25.0 %, nuclear 7.6 %, and hydro 2.7 %. With these percentages in mind, I assume that the peak of world oil production and the OPEC / non-OPEC crossover point will be important events in the Olduvai theory.

Oil is liquid and portable, and has high energy density. It is the major *primary* source of energy for Industrial Civilization. (Remember however, oil is not the most important *end-use* source of energy, discussed later.) A colleague (Walter Youngquist) and I have developed a new method of modeling and simulation and then used it to make a series of five forecasts of world oil production — a new forecast every year. Figure 1 shows the main results of the most recent forecast, i.e. Forecast #5 (Duncan, 2000b).

Figure 1. World, OPEC, and Non-OPEC Oil Production



Notes: (1) World oil production is forecast to peak in 2006. (2) The OPEC / non-OPEC crossover event occurs in 2008. (3) The OPEC nations' rate of oil production from 1985 to 1999 increased by 9.4 times that of the non -OPEC nations.

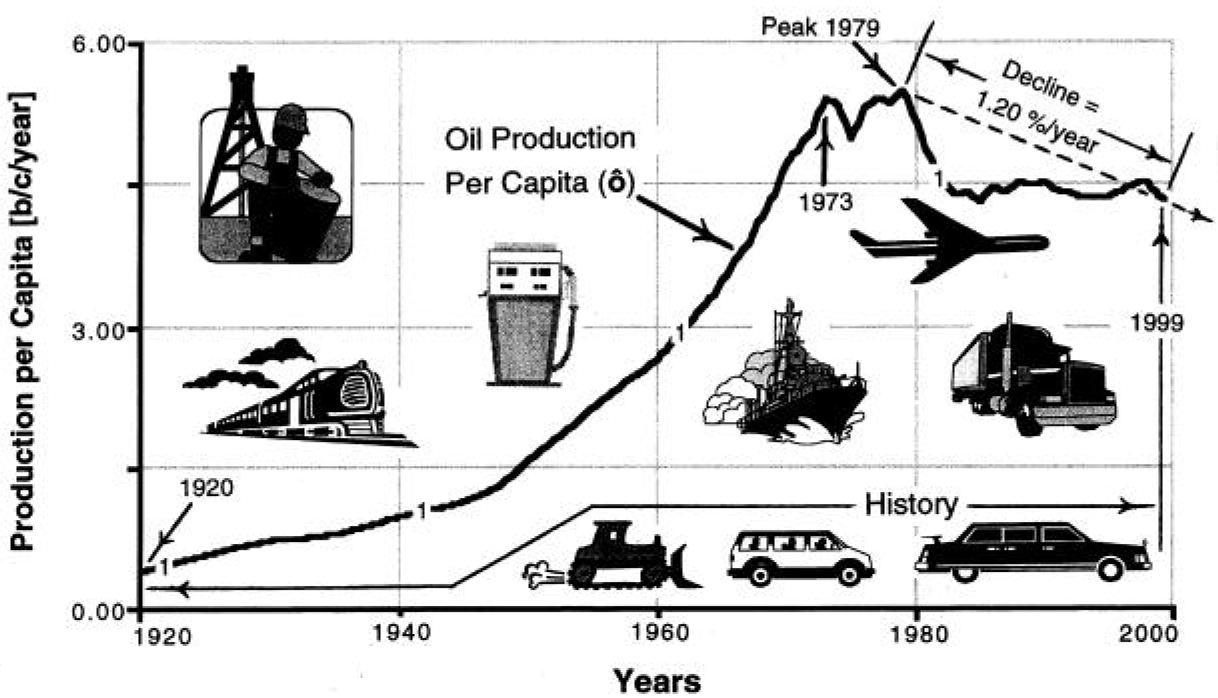
Figure 1 shows the historic world oil production data from 1960 to 1999 and my forecasts from 2000 to 2040. Note that the overall growth rate of oil production slowed from 1960 to 1999 (curve 1). In detail: The average rate of growth from 1960 to 1973 was a whopping 6.65 % / year. Next, from 1973 to 1979 growth slowed to 1.49 % / year. Then, from 1979 to 1999, it slowed yet further to a glacial 0.75 % / year. Moving beyond the historic period, Forecast #5 predicts that world oil production will reach its all-time peak in 2006. Then from its peak in 2006 to year 2040 world oil production will fall by 59.0 % — an average decline of 2.5 % / year during these 34 years.

The OPEC / non-OPEC crossover event is predicted to occur in 2008 (Figure 1, curves 2 & 3). This event will divide the world into two camps: one with surplus oil, the other with none. Forecast #5 presents the following scenario. (1) Beginning in 2008 the 11 OPEC nations will produce more than 50% of the world's oil. (2) Thereafter OPEC will control nearly 100% of the world's oil exports. (3) BP (2000) puts OPEC's "proved reserves" at 77.6% of the world total. (4) OPEC production from 1985 to 1999 grew at a strong average rate of 3.46 %/year. In contrast, non-OPEC production grew at sluggish 0.37 %/year during this same 14-year period.

The oil forecasting models, the application program to run them, and a User's Guide are all available free on the Internet (see Duncan, 2000a).

The peak of world oil production (2006) and the OPEC/non-OPEC crossover event (2008) are important to the 'Olduvai schema', discussed later. But first let us look at the ratio of world oil production and world population. Figure 2 shows the historic data.

Figure 2. World Average Oil Production per Capita: 1920-1999



Notes: (1) World average oil production per capita (ô) grew exponentially from 1920 to 1973. (2) Next, the average growth rate was near zero from 1973 to the all-time peak in 1979. (3) Then from its peak in 1979 to 1999, ô decreased strongly by an average of 1.20

%/year. (4) Typical response: *"You've gotta be kidding!"* (5) The little cartoons emphasize that oil is by far the major *primary* source of energy for transportation.

Figure 2 shows the world average oil production per capita from 1920 to 1999. The curve represents the ratio of world oil production (O) and world population (Pop): i.e. ô = O/(Pop) in barrels per capita per year (i.e. b/c/year). Note well that ô grew exponentially from 1920 to 1973. Next, growth was negligible from 1973 to the all-time peak in 1979. Finally, from its peak in 1979 to 1999, ô decreased at an average rate of 1.20 %/year (i.e., from 5.50 b/c in 1979 to 4.32 b/c in 1999).

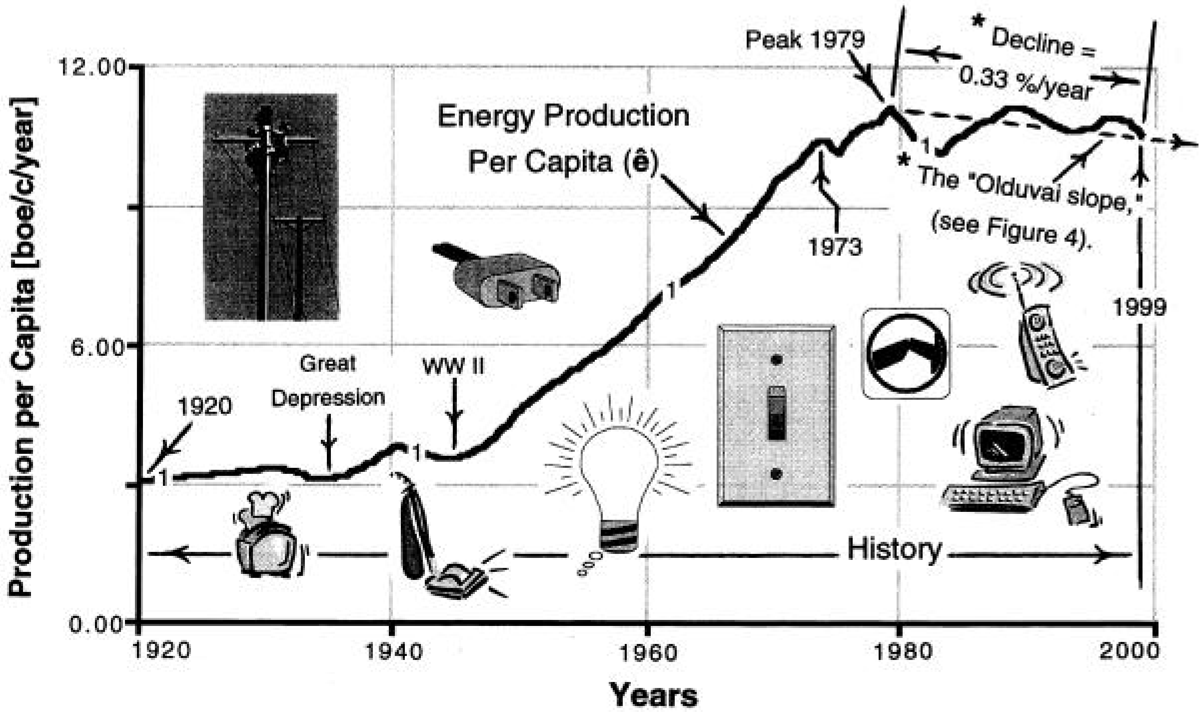
The 1979 peak and decline of world oil production per capita can be viewed on the Internet on page 11 of BP (2000). Not to be missed.

Bottom Line

Although world oil production (O) from 1979 to 1999 increased at an average rate of 0.75 %/year (Figure 1), world population (Pop) grew even faster. Thus world oil production per capita (ô) declined at an average rate of 1.20 %/year during the 20 years from 1979 to 1999 (Figure 2).

The main goals in this study, as was stated, are to describe, discuss, and test the Olduvai theory of Industrial Civilization against historic data. Applying White's Law, our metric (i.e. indicator) is the ratio of world total energy production (E) and world population (Pop): i.e., ê = E/(Pop). Figure 3 shows ê during the historic period.

Figure 3. World Energy Production per Capita: 1920-1999



Notes: (1) World average energy production per capita (ê) grew significantly from 1920 to its all-time peak in 1979. (2) Then from its peak in 1979 to 1999, ê declined at an average rate of 0.33 %/year. This downward trend is the "Olduvai slope", discussed later. (3) The tiny cartoons emphasize that the delivery of *electricity* to end-users is the *sin quo non* of the 'modern way of life'. Not hydrocarbons.

Observe the variability of ê in Figure 3. In detail: From 1920 to 1945 ê grew moderately at an average of 0.69 %/year. Then from 1945 to 1973 it grew at the torrid pace of 3.45 %/year. Next, from 1973 to the all-time peak in 1979, growth slowed to 0.64 %/year. But then suddenly — and for the first time in history — ê began a long-term decline extending from 1979 to 1999. This 20-year period is named the "Olduvai slope," the first of the three downside intervals in the "Olduvai schema."

Bottom Line

Although world energy production (E) from 1979 to 1999 increased at an average rate of 1.34 %/year, world population (Pop) grew even faster. Thus world energy production per capita (ê) declined at an average rate of 0.33 %/year during these same 20 years (Figure 3). See White's Law, top of this section.

Acknowledgments: As far as I know, credit goes to Robert Romer (1985) for being first to publish the peak-period data for world energy production per capita (ê) from 1900 to 1983. He put the peak (correctly!) in 1979, followed by a sharp decline through 1983, the last year of his data. Credit is also due to John Gibbons, et al. (1989) for publishing a graph of ê from 1950 to 1985. Gibbons, et al. put the peak in 1973. But curiously, neither of the above studies made any mention whatever about the importance of the peak and decline of world energy production per capita.

The 1979 peak and decline of world energy production per capita (ê) can be viewed on the Internet on page 40 of BP (2000).

EVOLUTION OF AN IDEA

> And what a glorious society we would have if men and women would regulate their affairs, as do the millions of cells in the developing embryo. — Hans Spemann, 1938

The seeds of the Olduvai theory were sowed long ago. The following items are a time-line sampling of the history of this important and vexing idea.

The Greek lyric poet Pindar (c. 522-438 BCE) wrote, "What course after nightfall? Has destiny written that we must run to the end?" (See Eiseley, 1970.)

Roman church father Quintus Tertullian (c. 160-230 CE) observed that suffering and misery can act as a negative feedback to population growth. "The strongest witness is the vast population of the earth to which we are a burden and she scarcely can provide for our needs; as our demands grow greater, our complaints against nature's inadequacy are heard by all. The scourges of pestilence, famine, wars, and earthquakes have come to be regarded as a blessing to overcrowded nations, since they serve to prune away the luxuriant growth of the human race." (See Hardin, 1993.)

Arabic scholar Ibn Khaldun (1332-1406) regarded "group solidarity" as the primary requisite for civilization. "Civilization needs the tribal values to survive, but these very same values are destroyed by civilization. Specifically, urban civilization destroys tribal values with the luxuries that weaken kinship and community ties and with the artificial wants for new types of cuisine, new fashions in clothing, larger homes, and other novelties of urban life." (See Weatherford, 1994.)

Joseph Granvill in 1665 observed that, although energy-using machines made life easier, they also made it more dependent. "For example, if artificial demands are stimulated, than resources must be consumed at an ever-increasing pace." (See Eiseley, 1970.)

But, as far as I know, it was the American adventurer and writer Washington Irving (1783-1859) who was first to realize that civilization *could* quickly collapse.

> Nations are fast losing their nationality. The great and increasing intercourse, the exchange of fashions and uniformity of opinions by the diffusion of literature are fast destroying those peculiarities that formerly prevailed. We shall in time grow to be very much one people, unless a return to barbarism throws us again into chaos. (Irving, 1822)

The first statement that I've found that Industrial Civilization *is likely to* collapse into a primitive mode came from the mathematical biologist Alfred Lotka.

> The human species … has swiftly and radically changed its character during the epoch in which our life has been laid. In this sense we are far removed from equilibrium ... [This] implies that a period of adjustment to equilibrium conditions lies before us, and he would be an extreme optimist to expect that such adjustment can be reached without labor and travail. … While such sudden decline [in population] … might appear as in accord with the eternal equities … Our descendants … will see poor compensation for *their* ills in the fact that *we* lived in abundance and luxury. (Lotka, 1925)

Polymath Norbert Wiener (1894-1964) wrote in 1950 that the best we can hope for the role of progress is that "our attempts to progress in the face of overwhelming necessity may have the purging terror of Greek tragedy."

> [America's] resources seemed inexhaustible [in 1500] … However, the existence of the new lands encouraged an attitude not unlike that of Alice's Mad Tea party. … As time passed, the tea table of the Americas had proved not to be inexhaustible … What many of us fail to realize is that the last four hundred years are a highly special period in the history of the world. … This is partly the result of increased communication, but also of an increased mastery of nature that … may prove in the long run to be an increased slavery to nature. (Wiener, 1950)

Sir Charles Galton Darwin wrote in 1953:

> The fifth revolution will come when we have spent the stores of coal and oil that have been accumulating in the earth during hundreds of millions of years. … It is obvious that there will be a very great difference in ways of life. … Whether a convenient substitute for the present fuels are found or not, … there will have to be a great change in ways of life. This change may justly be called a revolution … in that there is no likelihood of its leading to increases of population, but even perhaps to the reverse. (C. G. Darwin, 1953)

Sir Fred Hoyle in 1964 put it bluntly:

> We have or soon will have, exhausted the necessary physical prerequisites [necessary for maintaining a high-level civilization] so far as this planet is concerned. With coal gone, oil gone, high-grade metallic ores gone, no species however competent can make the long climb from primitive conditions to high-level technology. This is a one-shot affair. If we fail, this planetary system fails so far as intelligence is concerned. The same will be true of other planetary systems. On each of them there will be one chance, and one chance only. (Hoyle, 1964)

American biologist and writer Garrett Hardin in 1968 eloquently explained the human 'problematique' in terms of the *unmanaged* commons — i.e. the earth's atmosphere, pasturelands, forests, waters, and the human population. "Ruin is the destination toward which all men rush, each pursuing his own best interest in a [crowded] society that believes in the freedom of the commons. Freedom of the commons brings ruin to all." (Hardin, 1968)

WORLD MODELS, ETC.

> Perhaps the most widespread evil is the Western view of man and nature. Among us, it is widely believed that man is apart from nature, superior to it; indeed, evolution is a process to create man and seat him on the apex of the cosmic pinnacle. He views the earth as a treasury that he can plunder at will. And, indeed, the behavior of Western people, notably since the advent of the Industrial Revolution, gives incontrovertible evidence to support this assertion. — Ian McHarg, 1971

Jay Forrester of MIT in 1970 built a world model "to understand the options available to mankind as societies enter the transition from growth to equilibrium."

> What happens when growth approaches fixed limits and is forced to give way to some form of equilibrium? Are there choices before us that lead to alternative world futures? … Exponential growth does not continue forever. Growth of population and industrialization will stop. If man does not take conscious action to limit population and capital investment, the forces inherent in the natural and social system will rise high enough to limit growth. The question is only a matter of when and how growth will cease, not whether it will cease. (Forrester, 1971)

The basic behavior of Forrester's world model was overshoot and collapse. It projected that the material standard of living (MSL) would peak in 1990 and then decline through the year 2100. Moreover, measured by the MSL (i.e. the leading and lagging 30% points), the life expectancy of Industrial Civilization was about 210 years. (See Forrester, 1971, Figure 4-2.) He used the world model to search for social (i.e. cultural, "conscious action") policies for making the transition to sustainability.

> In our social systems, there are no utopias. No sustainable modes of behavior are free of pressures and stresses. … But to develop the more promising modes will require restraint and dedication to a long-range future that man may not be capable of sustaining. Our greatest challenge now is how to handle the transition from growth into equilibrium. The industrial societies have behind them long traditions that have encouraged and rewarded growth. The folklore and the success stories praise growth and expansion. But that is not the path of the future. (ibid., 1971)

The modeled world system indicated that sustainability could be achieved only when the following five social policies were applied together in 1970:

- Natural-resource-usage-rate reduced 75%
- Pollution generation reduced 50%
- Capital-investment generation reduced 40%
- Food production reduced 20%
- Birth rate reduced 30%

Critics (mostly economists) argued that such policies were e.g. "unrealistic" and "utopian." Fortunately, the project team was just then completing a two-year study using the more comprehensive 'World3' model. They too searched for social policies that might achieve sustainability in the world system. However, the World3 'reference run' (like Forrester's in 1971) also projected overshoot and collapse of the world system.

> *This is the World3 reference run, …. Both population POP and industrial output per* capita *IOPC grow beyond sustainable levels and subsequently decline. The cause of their decline is traceable to the depletion of nonrenewable resources.* (Meadows, et al., 1972, Figure 35)

The World3 'reference run' (1972, above) projected that the industrial output per capita (IOPC) would reach its all-time peak in 2013 and then would steeply decline through 2100. Moreover, the duration of Industrial Civilization (as measured by the leading and lagging IOPC 30% points) came out to be about 105 years.

I first presented the Olduvai theory more than 11 years ago at a meeting of the American Society of Engineering Educators in Binghamton, New York, as follows:

- The broad sweep of human history can be divided into three phases.
- The first, or pre-industrial phase was a very long period of equilibrium when simple tools and weak machines limited economic growth.
- The second, or industrial phase was a very short period of non-equilibrium that ignited with explosive force when powerful new machines temporarily lifted all limits to growth.
- The third, or de-industrial phase lies immediately ahead during which time the industrial economies will decline toward a new period of equilibrium, limited by the exhaustion of nonrenewable resources and continuing deterioration of the natural environment. (Duncan, 1989)

In 1992, twenty years after the first World3 study, the team members re-calibrated the model with the latest data and used it to help "envision a sustainable future." But —

> All that World3 has told us so far is that the model system, and by implication the "real world" system, has a strong tendency to overshoot and collapse. In fact, in the thousands of model runs we have tried over the years, overshoot and collapse has been by far the most frequent outcome. (Meadows, et al., 1992)

The updated World3 'reference run', in fact, gave almost exactly the same results as it did in the first study in 1972! For example: Industrial output per capita (IOPC) reached its all-time peak in 2014 (v. 2013 previously) and the duration of Industrial Civilization came out to be 102 years (v. 105 years previously).

Australian writer Reg Morrison likewise foresees that overshoot and collapse is where humanity is headed. In his scenario (i.e. no formal model), the world population rises to about 7.0 billion in the 2036. Thence it plunges to 3.2 billion in 2090 — an average loss of 71.4 million people per year (i.e. deaths minus births) during 54 years.

> Given the current shape of the human population graph, those indicators also spell out a much larger and, from our point of view, more ominous message: the human plague cycle is right on track for a demographically normal climax and collapse. Not only have our genes managed to conceal from us that we are entirely typical mammals and therefore vulnerable to all of evolution's customary checks and balances, but also they have contrived to lock us so securely into the plague cycle that they seem almost to have been crafted for that purpose. Gaia is running like a Swiss watch. (Morrison, 1999)

The foregoing discussions show that many respected professionals have reached conclusions that are consistent with the Olduvai theory, to which we now turn.

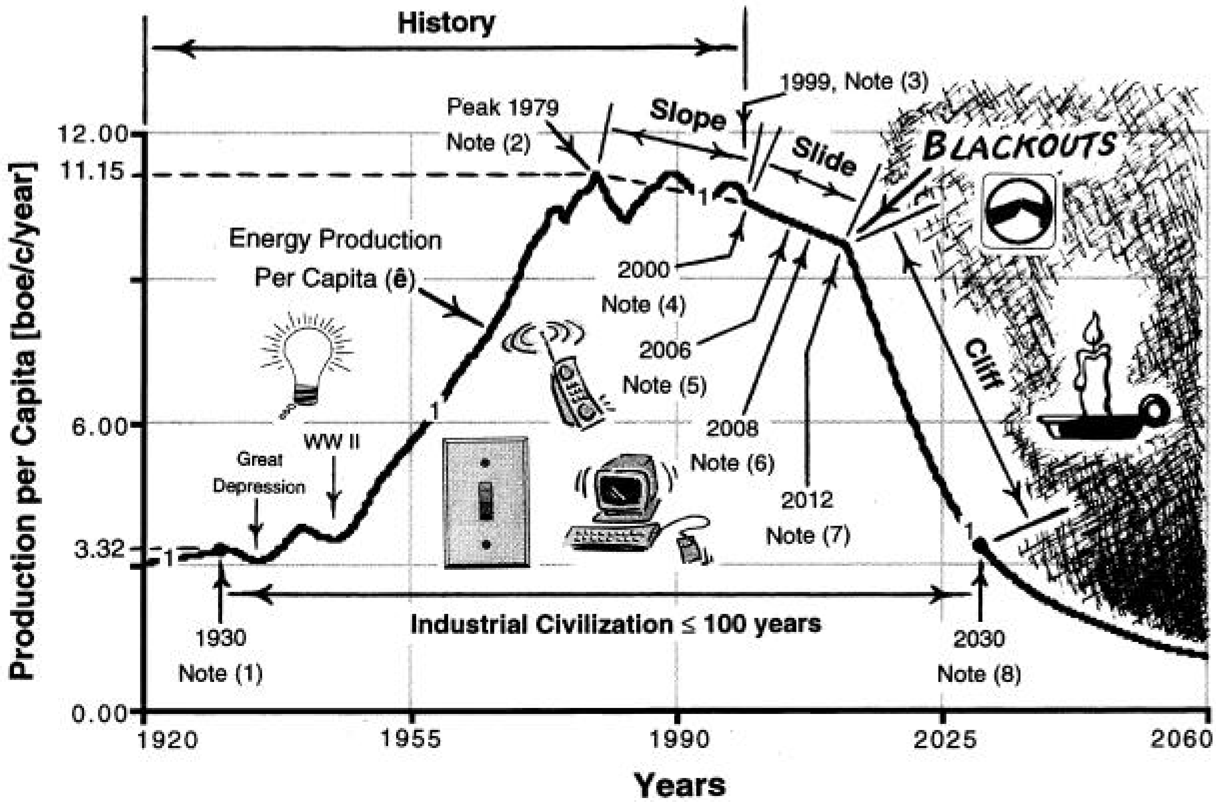
THE OLDUVAI THEORY: 1930-2030

> The earth's immune system, so to speak, has recognized the presence of the human species and is starting to kick in. The earth is attempting to rid itself of an infection by the human parasite. — Richard Preston, 1994

The Olduvai theory, to review, states that the life expectancy of Industrial Civilization is less than or equal to one hundred years, as measured by the world average energy production (use) per person: $\hat{e} = E/(Pop)$. The mathematical details are given in Duncan, 1993. The theory is based on two postulates. (1) The world is a closed system [i.e. energy exchange is OK, but not mass]. (2) The system tends to equilibrium by negative feedback [see Meadows, Morrison and Preston above]. Taken separately, these postulates are bland, but taken together the consequences are daunting.

Industrial Civilization, defined herein, began in 1930 and is predicted to end on or before the year 2030. The main goals for this section are threefold: (1) to discuss the Olduvai theory from 1930 to 2030, (2) to identify the important energy events during this time, and (3) to stress that Industrial Civilization = Electrical Civilization = the 'modern way of life.' Figure 4 depicts the Olduvai theory.

Figure 4. The Olduvai Theory: 1930-2030



Notes: (1) 1930 => Industrial Civilization began when (ê) reached 30% of its peak value. (2) 1979 => ê reached its peak value of 11.15 boe/c. (3) 1999 => The end of cheap energy. (4) 2000 => Start of the "Jerusalem Jihad." (5) 2006 => Predicted peak of world oil production (Figure 1, this paper). (6) 2008 => The OPEC crossover event (Figure 1). (7) 2012 => Permanent blackouts occur worldwide. (8) 2030 => Industrial Civilization ends when ê falls to its 1930 value. (9) Observe that there are three intervals of decline in the Olduvai schema: slope, slide and cliff — each steeper than the previous. (10) The small cartoons stress that electricity is the essential *end-use* energy for Industrial Civilization.

Figure 4 shows the complete Olduvai curve from 1930 to 2030. Historic data appear from 1930 to 1999 and hypothetical values from 2000 to 2030. These 100 years are labeled "Industrial Civilization." The curve and the events together constitute the "Olduvai schema." Observe that the overall curve has a pulse-like waveform — namely overshoot and collapse. Eight key energy events define the Olduvai schema.

Eight Events

The 1st event in 1930 (see Note 1, Figure 4) marks the beginning of Industrial Civilization when ê reached 3.32 boe / c. This is the "leading 30% point," a standard way to define the duration of a pulse. The 2nd event in 1979 (Note 2) marks the all-time peak of world energy production per capita and the beginning of the Olduvai 'slope.' The 3rd event in 1999 (Note 3) marks the end of cheap energy. The 4th event in 2000 (Note 4) marks the eruption of violence in the Middle East — i.e. the "Jerusalem Jihad." Observe that world energy use per capita (ê) declined at an average of 0.33 % / year during the 21 'slope' years from 1979 to 2000.

Next in Figure 4 comes the forecasted intervals in the Olduvai schema. The escalating violence in 2001 in the Middle East signals the beginning of the Olduvai 'slide'. The 5th event in 2006 (Note 5) marks the all-time peak of world oil production (see Figure 1, this paper). The 6th event in 2008 (Note 6) marks the OPEC crossover event when the 11 OPEC nations produce 51% of the world's oil and control nearly 100% of the world's oil exports (Figure 1). The year 2012 marks the end of the Olduvai 'slide,' wherein ê declines at 0.67 % / year from 2000 to 2012.

The 'cliff' is the third and final interval in the Olduvai schema. It begins with the 7th event in 2012 (Note 7) when an epidemic of permanent blackouts spreads worldwide, i.e. first there are waves of brownouts and temporary blackouts, then finally the electric power networks themselves expire. This is the so-named Olduvai "trigger event" when all the vital C^3 functions die. The 8th event in 2030 (Note 8, Figure 4) marks the fall of world energy production (use) per capita to the 1930 level. This is the lagging 30% point at which time Industrial Civilization has become history. The average rate of decline of ê is 5.44 % / year during the 18 'cliff' years from 2012 to 2030.

"The moving hand doth write, and then moves on." Decreasing electric reliability is now.

> The power shortages in California and elsewhere are the product of the nation's long economic boom, the increasing use of energy-guzzling computer devices, population

> growth and a slow down in new power-plant construction amid the deregulation of the utility market. As the shortages threaten to spread eastward over the next few years, more Americans may face a tradeoff they would rather not make in the long-running conflict between energy and the environment: whether to build more power plants or to contend with the economic headaches and inconveniences of inadequate power supplies. (Carlton, 2000)

> The electricity business has also run out of almost all-existing generating capacity, whether this capacity is a coal-fired plant, a nuclear plant or a dam. The electricity business has already responded to this shortage. Orders for a massive number of natural gas-fired plants have already been placed. But these new gas plants require an unbelievable amount of natural gas. This immediate need for so much incremental supply is simply not there. (Simmons, 2000)

As I have emphasized, electricity is crucial to Industrial Civilization, i.e. the 'modern way of life.' Consider the following: In 1999, about 42% of the world's *primary* sources of energy were used to 'generate' electricity. However, the overall process of transforming thermal energy into electricity and then distributing it to the customers is only about 33% efficient (i.e. 67% of the primary energy is 'wasted'). Next there is the matter of how the customers themselves use the electricity. For instance: About 85% of the electricity goes for space heating, electric lighting, and mechanical motion (i.e. 'shaft power') — functions that could actually be powered directly by the hydrocarbon fuels. (Just imagine the steam-powered and gas-and-kerosene-lit cities such as New York, London, and Paris before Thomas Edison.) But now comes the crux of the matter. It is the functions powered by the remaining 15% of the electricity that (1) *do require* electricity, and (2) *are vital* to the 'modern way of life': namely communication, computation, and control — i.e. the C^3 functions. *And the power for the C^3 functions can't be unbundled!* If the grids are lost, then Industrial Civilization is paralyzed — no industry, no commerce, no jobs, no food. Industrial Civilization, as it were, is living at the mercy of C^3 life-support.

Example

The world 'consumed' a total of 3.6×10^{20} joules (J) of primary energy in 1999 (BP, 2000). For convenience, let's call this 100% of the primary energy consumed that year. Of this, a huge 42% of the primary energy was used to generate and distribute electricity. But that process is only 33% efficient. Thus only 13.9% of the world's primary energy (i.e. 0.33 * 0.42 = 13.9%) was actually (transformed to and) consumed as electricity. Further, the C^3 functions used just 15% of the total electricity consumed. This means that all of Industrial Civilization is, so to say, hanging by the unraveling thread of electric power production and distribution. *Bottom Line:* Even though the crucial C^3 functions required only 15% of the electricity distributed by the electric grids, 42% of the world's *primary* energy had to be consumed to keep the grids energized. Otherwise, Industrial Civilization would have been paralyzed — instantly.

With apologies to George Orwell and the 2nd Law of Thermodynamics — All joules (J) of energy are equal, but some joules are more equal than others.

Au Courant King Kilowatt!

Question

Where will the Olduvai die-off occur? *Response:* Everywhere. But large cities, of course, will be the most dangerous places to reside when the electric grids permanently fail. There are millions of people densely packed in high-rise buildings, surrounded by acres-and-acres of blacktop and concrete: no electricity, no work, and no food. Thus the urban areas will rapidly depopulate when the electric grids die. In fact the danger zones are already mapped out. (See Living Earth, 1996, available on the Internet.) Specifically: The big cities stand out as bright yellow-orange dots on NASA's satellite mosaics (i.e. pictures) of the earth at night. These planetary lights blare out "Beware," "Warning," and "Danger." The likes of Los Angeles and Chicago and Baltimore-to-Boston, London and Paris and Brussels-to-Berlin, Bombay and Hong Kong and Osaka-to-Tokyo are all unsustainable hot spots.

SUMMARY AND CONCLUSIONS

The theory of civilization is traced from Greek philosophy in about 500 BCE to a host of respected scientists in the 20th century. For example: The 'reference runs' of two world simulation models in the 1970s put the life expectancy of civilization between about 100 and 200 years. The Olduvai theory is specifically defined as the ratio of world energy production and world population. It states that the life expectancy of Industrial Civilization is less than or equal to 100 years: from 1930 to 2030. The theory is tested against historic data from 1920 to 1999.

Although all primary sources of energy are important, the Olduvai theory identifies electricity as the quintessential end-use energy of Industrial Civilization. World energy production per capita increased strongly from 1945 to its all-time peak in 1979. Then from 1979 to 1999 — for the first time in history — it decreased from 1979 to 1999 at a rate of 0.33 %/year (the Olduvai 'slope,' Figure 4). Next from 2000 to 2012, according to the Olduvai schema, world energy production per capita will decrease by about 0.70 %/year (the 'slide,' Figure 4). Then around year 2012 there will be a rash of permanent electrical blackouts — worldwide. Consequently the vital C^3 functions — communication, computation, and control — will be lost. This, in turn, will cause energy production per capita by 2030 to fall to 3.32 boe/year, the same value it had in 1930. The rate of decline from 2012 to 2030 is 5.44 %/year (the 'cliff,' Figure 4). Hence, by definition, the duration of Industrial Civilization is less than or equal to 100 years.

The Olduvai 'slide' from 2000 to 2012 (Figure 4) may resemble the "Great Depression" of 1929 to 1939: unemployment, breadlines, and homelessness. As for the Olduvai 'cliff' from 2012 to 2030 — I know of no precedent in human history.

A keen question is posed: "Why are you confident about the Olduvai theory?" My response: "Because Mother Nature then solves for us the (apparently) insuperable problem of the Tragedy of the Unmanaged Commons, which the human race seems either incapable or unwilling to solve for itself."

Governments have lost respect. World organizations are ineffective. Neo-tribalism is rampant. The population is over six billion and counting. Global warming and emerging diseases are headlines. The reliability of electric power networks is falling. And the instant the power goes out, you are back in the Dark Age.

If God made the Earth for human habitation, then He made it for the Stone Age mode of habitation. The Olduvai theory is thinkable.

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