The Olduvai Theory

Energy, Population, and Industrial Civilization

by Richard C. Duncan

Abstract

The Olduvai Theory states that the life expectancy of industrial civilization is approximately 100 years: circa 1930-2030. Energy production per capita *(e)* defines it. The exponential growth of world energy production ended in 1970 (Postulate 1 is verified). Average *e* will show no growth from 1979 through circa 2008 (Postulate 2 is confirmed from 1979 through 2003). The rate of change of *e* will go steeply negative circa 2008 (Postulate 3). World population will decline to about two billion circa 2050 (Postulate 4). A growing number of independent studies concur (see text).

[Key Words*: Olduvai Theory; Henry Adams; energy and population; exponential growth; permanent blackouts; overshoot and collapse.*]

Introduction

The Olduvai Theory states that the life expectancy of industrial civilization is approximately 100 years: circa 1930-2030. It is defined by the ratio of world energy production and population *(e)*. Four postulates follow:

1. The exponential growth of world energy production ended in 1970.
2. Average *e* will show no growth from 1979 to circa 2008.
3. The rate of change of *e* will go steeply negative circa 2008.
4. World population will decline proximate with *e*.

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This paper accomplishes four goals:

The first goal is to show that from 1893 through 1949 three distinguished scholars formulated a comprehensive Olduvai scenario.

The second goal is threefold: 1) electrical power is crucial end-use energy for industrial civilization;[1] 2) the big blackouts are inevitable; and 3) the proximate cause of the collapse of industrial civilization, if and when it occurs, will be that the electric power grids go down and never come back up.

I first presented the Olduvai Theory at an engineering conference entitled, "Science, Technology, and Society" (Duncan, 1989). My paper was well received and a lengthy discussion followed — even though I had no data to support it at the time. A few years later I had gathered eight (8) historical data points to backup the theory (Duncan, 1993). Three years after that I showed that it held up against the world energy and population data from 1950 to 1995 (Duncan, 1996). Next tested in 2000, the theory was supported by data from 1920 to 1999 (Duncan, 2000, 2001). The third goal of this paper is to extend this series of tests by using data from 1850 through 2003.

The fourth goal is twofold: 1) detail and describe the Olduvai Theory from 1930 to 2030, and 2) document that a growing number of studies concur with Postulate 4.

Three Scouts

> *There is no comprehensive substitute for oil in its high-energy density, ease of handling, myriad end-uses, and in the volumes in which we now use it. The peak of world oil production and then its irreversible decline will be a turning point in Earth history with worldwide impact beyond anything previously seen. And that event will surely occur within the lifetimes of most people living today.* (Youngquist, 2004)

An Olduvai scenario of industrial society was envisioned by historian Henry Adams in 1893, quantified by architect Frederick Ackerman in 1932, and graphed by geophysicist King Hubbert in 1949. A summary follows.

HENRY ADAMS, Historian (1838-1918) – great grandson of the second President and grandson of the sixth: I first became aware of Henry Adams' work in 2002 while reading David E. Nye's masterpiece *Electrifying America.*

Henry Adams defined energy broadly to include not only steam engines or electricity but also any force capable of organizing and directing people.

> *Adams concluded that electrification was part of a larger process of historical acceleration, which would lead to an inevitable social decline. … It seemed probable that the ultimate result of exploiting new energy systems would be the apocalyptic end of history itself.* (Nye, 1990, p. 142-3)

Adams' goal was to discover a succinct law of history as outlined in his book *The Education of Henry Adams* (Adams, 1907). It was at the Chicago World's Fair in 1893 where he first theorized that "forces totally new" – especially electric power and incandescent lighting – would "accelerate society into chaos and ruin."

> *The new American – the child of incalculable coal-power, chemical power, electric power, and radiating energy, as well as of new forces yet undetermined – must be a sort of god compared with any former creation of nature. … The new forces would educate. … The law of acceleration was definite … No scheme could be suggested to the new American, and no fault needed to be found, or complaint made; but the next great influx of new forces seemed near at hand, and its style of education promised to be violently coercive.* (Adams, 1907, Chap. 34)

Ernest Samuels (1973) edited Adams' book and forcefully summed it up.

> *Even in his own day he saw the eighteenth century American dream of unlimited opportunity and indefinite progress turning into a waking nightmare of the moral dilemmas of a capitalist society. He saw too that though science was indeed making tremendous advances in the conquest of Nature, winning every battle in that age-old contest, the odds were growing that a dehumanized mankind might lose the war.* (p. vii)

Henry Adams' farsightedness was and is amazing. He is buried in Rock Creek Cemetery in Washington, DC and his ideas are now resonating worldwide – but not yet in the U.S. capital.

FREDERICK LEE ACKERMAN**,** Architect (1878-1950): In 1919, Ackerman was a founding member of the Technical Alliance (later Technocracy Inc.). The group consisted of a broad spectrum of eminent professionals. In 1932 Ackerman published his seminal paper "The Technologist Looks at the Depression" wherein he – like Henry Adams before – observed that new energies were accelerating social change.

From about 4000 B.C.E. to 1750 C.E., Ackerman noted, the common welfare was limited to the work that man could do with his hands and a few crude tools.

Whence the Name 'Olduvai'?

Olduvai Gorge is an archaeological site in the eastern Serengeti Plains in northern Tanzania. The gorge is a very steep-sided ravine roughly 30 miles long and 295 ft. deep. Exposed deposits show rich fossil fauna, many hominid remains and items belonging to one of the oldest stone tool technologies, called Olduwan. The objects recovered date from 2,100,000 to 15,000 years ago.

The name of this premier site for studying the Stone Age has been taken to label the theory that industrial civilization will soon collapse and send humankind into precipitous decline.

Olduvai Gorge is best known as the site where, in 1959, the discoveries of Mary and Louis Leakey changed paleontology to focus on Africa, rather than Asia, as the region of human origins.

The Oxford Dictionary of Scientists (Oxford University Press, 1999) states: "Leakey's work has not only provided evidence for the greater age of humans but suggests that Africa, and not as was previously thought, Asia, may have been the original center of human evolution."

Social change, he concluded, involves a change in the techniques whereby people live.

> *We shall define as a "social steady state" any society in which the quantity [of energy expended] per capita … shows no appreciable change as a function of time. … On the other hand a society wherein … the average quantity of energy expended per capita undergoes appreciable change as a function of time is said to exhibit "social change." … Upon this basis we can measure quantitatively the physical status of any given social system. … The energy per capita [equals the] the total amount [of energy] expended divided by the population.* (Ackerman, 1932, p. 18-19)

Ackerman's Law is expressed by the ratio: e = Energy/Population.

It is important to acknowledge that in 1943 anthropologist Leslie A. White independently discovered what is now properly designated Ackerman's Law.[2]

M. KING HUBBERT, Geophysicist (1903-1989): In 1949 King Hubbert noted that world energy consumption per capita, *e,* after historically rising very gradually from about 2,000 to 10,000 kilogram calories per day, then increased to a much higher level in the 19th century. Further, he believed it possible for global society to maintain a high level of *e* indefinitely (later he labeled this "Course I"). But he also realized that society could permanently collapse back to "the agrarian level of existence" (later he labeled this "Course III").

Hubbert published sketches of Course III (overshoot and collapse) many times after 1949. And, although he kept the general shape of the curves the same, he successively decreased his estimate of when the peak of *e* would occur. Namely: In his original paper he put the peak of *e* in 2400 C.E. (Hubbert, 1949); in his next version he put the peak in 2360 C.E. (Hubbert, 1962); and in his final version he put the peak in 2150 C.E. (Hubbert, 1976). Thus between 1949 and 1976 Hubbert's "most dismal Course III" became successively bleaker by some 250 years.

The historical data through 2003 (shown later as curve 2, Figure 2) now rules out Hubbert's most optimistic Course I. This leaves global society with only two feasible futures: Course II (an orderly decline of *e* to a medium steady state) and Course III (collapse to the agrarian level of existence).

Linking the "scouts" together: Henry Adams in about 1915 gave the copyright to his book *Mont-San-Michele and Chartres* to the American Institute of Architects whereon they published it. At that time Frederick Ackerman was a distinguished member of the Institute. Further, both Frederick Ackerman and King Hubbert were close friends and prominent members of Technocracy Inc. Thus the intellectual chain linking Adams to Ackerman to Hubbert is complete.

Electromagnetic Civilization

> *For systems theorists the first message of their eerily smooth distribution curves is clear: big blackouts are a natural product of the power grid. The culprits that get blamed for each blackout – lax tree trimming, operators who make bad decisions – are actors in a bigger drama, their failings mere triggers for disasters that in some strange ways are predestined. In this systems-level view, massive blackouts are just as inevitable as the mega quake that will one day level much of Tokyo.* (Fairley, 2004)

This section stresses that 1) affordable electric power is crucial for modern living (all agree); 2) big blackouts are inevitable (power system engineers agree); 3) permanent blackouts are coming ("unthinkable").

1) King Kilowatt

Electricity is the most versatile and convenient end-use energy ever put to use by humanity. But one catch is that electricity is "everywhere and nowhere." Think of all the energized switches, outlets, and wires in an "empty" room plus the electromagnetic waves that pervade it at the speed of light (AM, FM, TV, cell phone, etc.). Then there is the vastly greater expanse of man-made electromagnetic energy that envelops the planet and radiates out into the Galaxy.[3]

Every power plant generates electromagnetic waves. From there they follow countless miles of high-voltage wave guides (commonly called "wires" or "lines") at near the speed of light to numerous customer loads: heaters, motors, telephones, lights, antennas, radios, televisions, fiber-optic systems, the

Internet, etc. We constantly "swim" through this sea of electromagnetic energy just as fishes swim through water. And, like water to fishes, this ethereal energy is vital to modern civilization.

By tallying the amount of primary energy used to generate electric power we find that electricity wins hands down as our most important end-use energy. To wit: I estimate that 7% of the world's oil is consumed by the electric power sector, 20% of the world's natural gas, 88% of the coal, and 100% each for nuclear and hydroelectric power. The result is that electric power accounts for 43% of the world's end-use energy compared to oil's 35%.

The critical role that electricity plays in the United States is likewise telling. Out of the total end-use energy consumed in each of the social sectors in 2003:

1) 0.2% was electricity in the Transportation sector,

2) 33.3% in the Industrial sector,

3) 65.9% in the Residential sector, and

4) 76.2% in the Commercial sector (EIA, 2004).

2) Big Blackouts Are Inevitable

The second catch is that electricity is generated, transmitted, and distributed by a complex, far-flung, costly, and fragile infrastructure.

The electric power networks are the largest, most complex machines ever constructed. They have been built, rebuilt, and interconnected over many decades with a baffling variety of hardware, software, standards, and regulations. The ravenous input nodes must be continuously fed with immense amounts of primary energy and then the output nodes deliver electromagnetic energy to myriad customer loads.

Between the input and output nodes are power plants, substations, and transmission and distribution lines and towers.

Inevitably the old equipment wears out or becomes obsolete so highly educated and skilled personnel are needed to maintain the grids.

Then there are power control centers that monitor and manage the generation, transmission, and distribution of electric power over local, regional, and super-regional areas. Each control center has numerous computers, databases, and special software to monitor and control the flow of power. Thoroughly trained and dedicated operators are essential to keep the grids going 24/7/365.

Much faster response times are provided by "protective relays" that instantly trip for abnormal conditions, such as short circuits on high-voltage power lines.

Thus, except for lightning strikes and tornadoes, it might seem that the power networks would always operate reliably, thus completely avoiding big blackouts.

But that is false. Power control specialists J. Apt and L. B. Lave (2004) have warned:

> *Data for the last four decades show that blackouts occur more frequently than theory predicts, and they suggest that it will become increasing expensive to prevent these low-probability, high-consequence events. The various proposed "fixes" are expensive and could even be counterproductive, causing future failures because of some unanticipated interaction.*

3) Permanent Blackouts Are Coming

The third catch, according to the Olduvai Theory, is that sooner or later the power grids will go down and never come back up.[4] The reasons are many.

The International Energy Agency (IEA, 2004) estimates that the cumulative worldwide energy investment funds required from 2003 to 2030 would be about $15.32 trillion (T, US 2000 $) allocated as follows:

1. Coal: $0.29T (1.9% of the total),
2. Oil: $2.69T (17.6%),
3. Gas: $2.69T (17.6%),
4. Electricity: $9.66T (63.1%).

Thus the IEA projects that the worldwide investment funds essential for electricity will be 3.7 times the amount needed for oil alone, and much greater than all of that required for oil, gas, and coal combined.

The OT says that the already debt-ridden nations, cities, and corporations will not be able to raise the $15.32 trillion in investment funds required by 2030 for world energy. (Not to mention the vastly greater investment funds required for agriculture, roads, streets, schools, railroads, water resources, sewer systems, and so forth.)

Furthermore, because of the rapidly rising cost of electricity, the increasingly impoverished customers won't be able to pay their electric bills. Worse yet, the really desperate ones will illegally wire directly to the low-voltage power lines, so without a wattmeter to record their usage they won't even have any bills to pay.

We will return to this pivotal topic later, but first I will use the most recent data now available to test OT Postulates 1 and 2.

World Energy and Population: the Basis

During the last two centuries we have known nothing but exponential growth and in parallel we have evolved what amounts to an exponential-growth culture, a culture so heavily dependent upon the continuance of exponential growth for its stability that it is incapable of reckoning with problems of no growth. (M. King Hubbert, 1976, p. 84)

The Olduvai Theory is based on time-series data of world energy production and population; all data are freely available on the Internet. The data are arrays of discrete numbers year-on-year, not continuous functions of time. Hence the difference calculus must be used, not the infinitesimal calculus. Postulates 1 and 2 require that we distinguish intervals of linear growth from those of exponential growth.[5, 6]

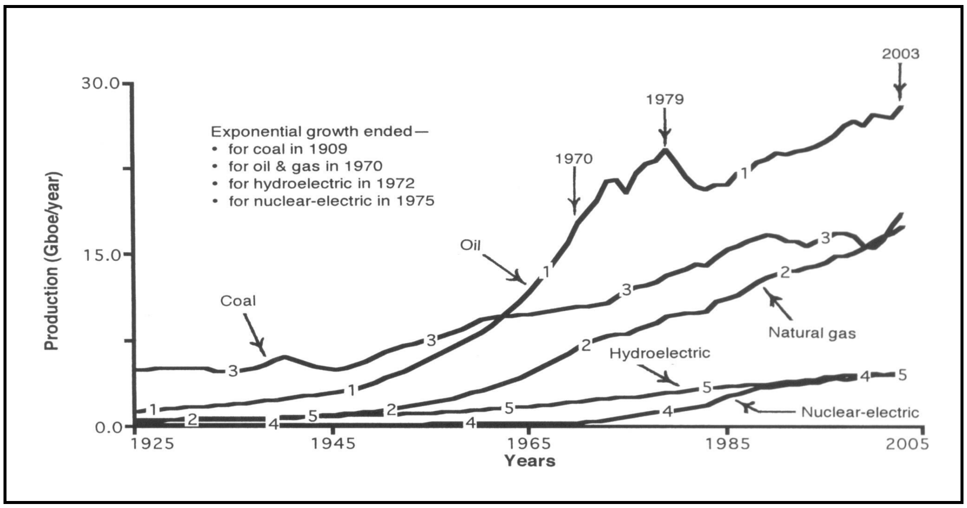

Figure 1. World production of the five major sources of energy. All curves are scaled in 'billion barrels of oil equivalent' (Gboe). Data sources: Romer (1985) for 1850-1964; British Petroleum (2004) for 1965-2003.

FIVE MAJOR SOURCES OF ENERGY

Our energy database for testing the OT ranges from 1850 through 2003 (Romer, 1985; British Petroleum, 2004). However it is more effective to focus on the years from 1925 through 2003 for world oil, natural gas, coal, nuclear, and hydroelectric energy production – Figure 1.[7]

Commercial oil production was underway before 1833 in the Chechen Republic (using shovel-dug wells; Iastratov, 2004). Hence, if we assume that it began in 1833 and grew exponentially up to 1850, then world oil production grew exponentially at an average of 8.8%/y during the 137-year interval from 1833 to 1970. After that production slowed to various linear rates of growth and decline from 1970 to 2003 (curve 1).

World natural gas production began in about 1880 and grew exponentially at 6.8%/y during the 90-year interval from 1880 to 1970. Thereafter it grew at a 2.7%/y linear rate from 1970 to 2003 (curve 2).

Coal was burned for cooking and space heating ever since the 12th Century, but it was not used for mechanical work until about 1700 (Savery's steam engine). Thus if we assume that it began in 1700 and grew exponentially up to 1850, then coal production grew exponentially at about 4.3%/y during the 209-year interval from 1700 to 1909. This was followed by several intervals of linear growth and decline from 1909 to 2003 (curve 3).

Nuclear-electric energy production began in 1955 (in Britain) and grew exponentially at 29.7%/y from 1955 to 1975. This was succeeded by three intervals of linear growth and decline from 1975 to 2003 (curve 4).

Hydroelectric energy production began in about 1890 (at Niagara Falls, USA) and grew exponentially at 15.4%/y from 1890 to 1912, followed by exponential growth at 3.6%/y from 1912 to 1972. Next came linear growth from 1972 to 2000 and decline from 2000 to 2003 (curve 5).

Testing Postulate 1 is facilitated by ranking the five sources of energy production by the duration of their intervals of exponential growth:

1. Coal grew exponentially for 209 years: 1700-1909.

2. Oil grew exponentially for 137 years: 1833-1970.

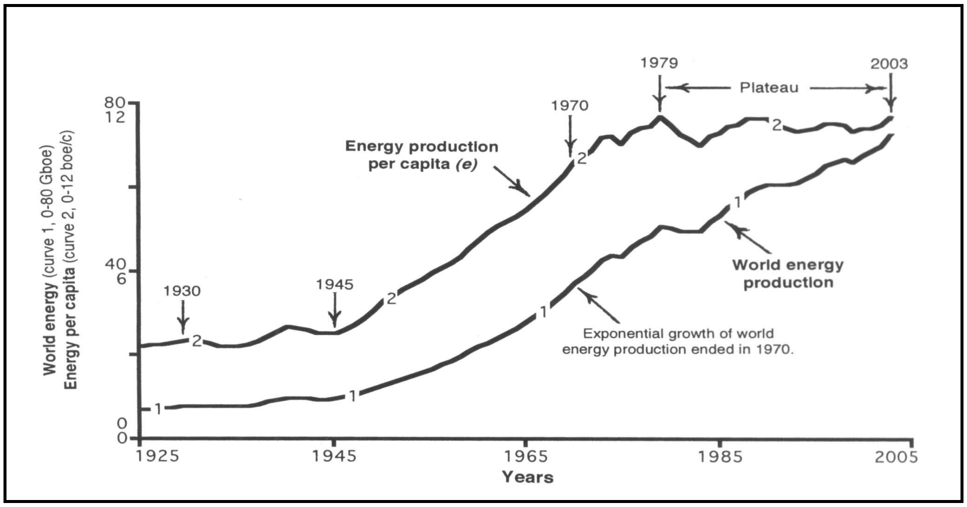

Figure 2. World energy production and energy production per capita. Data sources: 1) for energy – Romer (1985) for 1850-1964 and British Petroleum (2004) for 1965-2003; 2) for population – UN (2004) for 1850-1949 and USCB (2004) for 1950-2003.

3. Natural gas grew exponentially for 90 years: 1880-1970.

4. Hydroelectric energy grew exponentially for 82 years: 1890-1972.

5. Nuclear-electric energy grew exponentially for 20 years: 1955-1975.

Note well that none of the five sources of primary energy production grew exponentially after 1975. *Postulate 1 is partly verified (continued below).*

Q: So is exponential growth passé on this planet? My response: There is, I recognize, the possibility that world coal and/or nuclear-electric energy production could grow exponentially for very brief periods in the future, but that option does not exist for oil, natural gas, or hydroelectric energy production.

WORLD TOTAL ENERGY PRODUCTION AND ENERGY PRODUCTION PER CAPITA

By combining world oil, natural gas, coal, nuclear, and hydroelectric energy production (discussed above), we get the world total energy production. The portion from 1925 through 2003 is shown by curve 1, Figure 2.

World total energy production grew exponentially at about 4.6%/y from 1700 to 1909. Next it grew linearly at 2.2%/y from 1909 to 1930 and 1.5%/y from 1930 to 1945. Subsequently it surged exponentially at 5.5%/y from 1945 to 1970. This was followed by linear growth at 3.5%/y from 1970 to 1979. Thereafter world total energy production slowed to linear growth of about 1.5%/y from 1979 to 2003. *Postulate 1 is verified.*

World population is the essential other half of the energy-population matrix, but it is omitted from Figure 2 to avoid clutter. Described in numbers: World population grew linearly at an average of 0.5%/y from 1850 to 1909; 0.8%/y from 1909 to 1930; 1.0%/y from 1930 to 1945; 1.7%/y from 1945 to 1970; 1.8%/y from 1970 to 1979; and 1.5%/y from 1979 to 2003 (UN, 2004; USCB, 2004).

Comparing the foregoing numbers: World total energy production easily outpaced world population growth from 1700 to 1979, but then from 1979 through 2003 total energy production and population growth went dead even at 1.5%/y each.

World total energy production per capita, *e,* grew exponentially at 3.9%/y from 1700 to 1909. Thereafter it grew at linear rates of 1.4%/y from 1909 to 1930; 0.5%/y from 1930 to 1945; 3.7%/y from 1945 to 1970; 1.7%/y from 1970 to 1979; and 0.0%/y (i.e., zero net growth, called the 'Plateau') from 1979 to 2003 – curve 2, Figure 2.

Observe in Figure 2 that average *e* did not grow at all from 1979 to 2003. *Postulate 2 is confirmed from 1979 to 2003.*

The Olduvai Theory

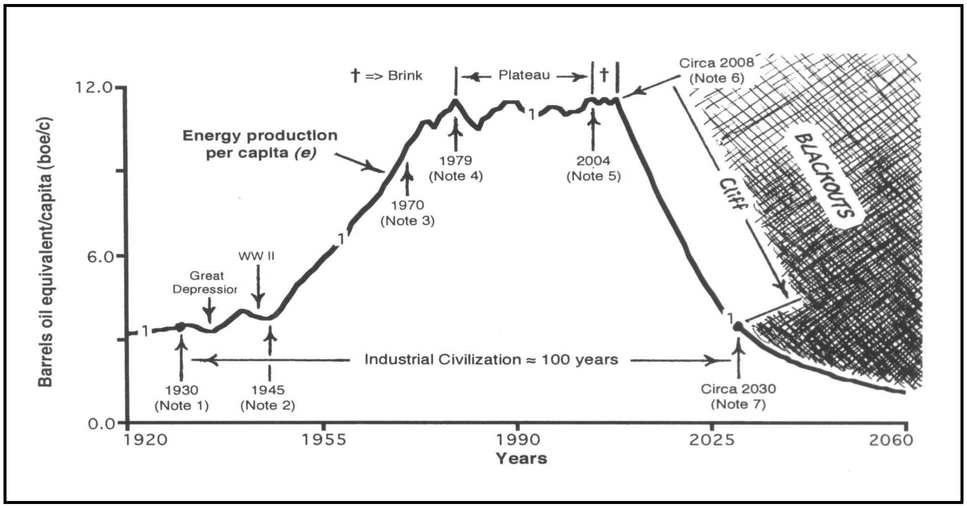

Figure 3. The Olduvai Theory: 1930-2030. Notes: (1) 1930 => Industrial civilization begins; (2) 1945 => Very strong growth begins; (3) 1970 => Growth begins to slow; (4) 1979 => The no-growth "Plateau" begins; (5) 2004 => The "Brink" begins; (6) Circa 2008 => The "Cliff" begins; and (7) Circa 2030 => Industrial civilization ends. Data sources: 1) for energy – Romer (1985) for 1850-1964, British Petroleum (2004) for 1965-2003, and Duncan (this paper) for 2004-2060; 2) for population—UN (2004) for 1850-1949, USCB (2004) for 1950-2004, and Duncan (this paper) for 2005-2060.

> *Many industrialized nations are now growing rapidly and placing ever-greater demands on world resources. Many of those resources come from the presently underdeveloped countries. What will happen when the resource-supplying countries begin to withhold resources because they foresee the day when their own demand will require the available supplies? ... Will the developed nations stand by and let their economies decline while resources still exist in other parts of the world? Will a new era of international conflict grow out of pressures from resource shortage?* (Forrester, 1971, p. 70)

The Olduvai Theory states that the life expectancy of industrial civilization is approximately 100 years: circa 1930-2030. Ackerman's ("White's") Law defines it: *e = Energy/Population.* The duration of industrial civilization is measured by the time in years from when *e* reaches 30% of its maximum value to the time when *e* falls back to that value. The OT is illustrated in Figure 3.

Seven events: The 1st event in 1930 (Note 1, Figure 3) marks the beginning of industrial civilization where *e* first reached 30% of its maximum value. The 2nd event in 1945 (Note 2) marks the beginning of very fast growth. The 3rd event in 1970 (Note 3) marks the beginning of slower growth. The 4th event in 1979 (Note 4) marks the start of a rough *Plateau* of no growth. The 5th event in 2004 (Note 5) marks the beginning of the *Brink.* The 6th event circa 2008 (2006-2012, Note 6) marks the edge of the *Cliff* where *e* begins a precipitous decline. The 7th event circa 2030 (Note 7) is the "lagging 30% point" when *e* falls back to 30% of its maximum value. This puts the duration of industrial civilization at approximately 100 years.

Seven intervals: 1) From 1930 to 1945 *e* shows irregular growth during the Great Depression and World War II.[8] 2) The strong growth from 1945 to 1970 correlates with the strong growth in world oil and natural gas production. 3) The slowing growth of *e* from 1970 to 1979 reflects slackening oil production. 4) The rugged *Plateau* from 1979 to 2003 shows that energy production ran neck-in-neck with population growth. 5) The *Brink* from 2004 to circa 2008 represents the energy industry's struggle to keep up with rising demand. 6) The *Olduvai Cliff* from circa 2008 to 2030 correlates with a spreading epidemic of permanent blackouts. 7) From 2030 onward society approaches the agrarian level of existence.

The most reliable leading indicator of the OT Cliff event, if and when it happens, will be brownouts and rolling blackouts.

WORLD POPULATION SCENARIOS

> *The resource wars will run their courses, and populations will crash. The journey back to 'natural' levels of world population will not be a joyous one. Have policy-makers begun to grasp the scale of the problem that confronts*

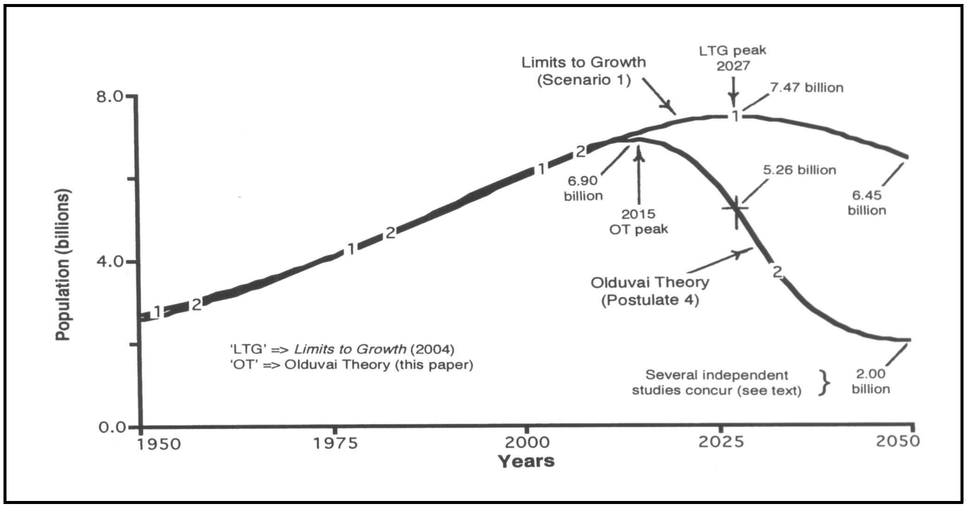

Figure 4. Two world population scenarios. Data sources: Curve 1—Meadows et al. (2004); Curve 2 – USCB (2004) for 1950-2004, and Duncan (this paper) for 2005-2050.

them? Are they still dazzled by the contention that rates of increase are slowing, not grasping that all the time the numbers are mounting up? (Stanton, 2003)

Two scenarios of world population are illustrated in Figure 4.[9] The first is based on a system dynamics model that was recently updated and tested with many alternative policies.[10] The second is based on some of my previous studies including nine forecasts of world oil production. Details follow.

1. Limits to Growth: The 30-Year Update (2004)

In 1970 The Club of Rome sponsored Phase One of the "Project on the Predicament of Mankind." Dr. Dennis Meadows of MIT directed a team of 17 scholars that worked for two years to complete it. "The study examined the five basic factors that determine, and therefore, ultimately limit, growth on this planet – population, agricultural production, natural resources, industrial production, and pollution."

Phase One of the study was published in *The Limits to Growth* (Meadows et al., 1972). That study was updated and published in *Beyond the Limits* (Meadows et al., 1992). In turn, the 1992 study was updated in 2002 and published in *Limits to Growth: The 30-Year Update* (Meadows et al., 2004).

The 30-year update is coded in 241 system dynamics equations. The main output of the model depicts 10 scenarios, and the key variables for each are plotted out over time. Depending on the assumptions, the LTG model can produce many different scenarios ranging from the deep impoverishment of society to a high level of human welfare extending far into the future.

Meadows et al. (2004) describe their reference scenario:

> *The world society proceeds in a traditional manner without any major deviation from the policies pursued during most of the twentieth century. Population and production increase until growth is halted by increasingly inaccessible nonrenewable resources. Ever more investment is required to maintain resource flows. Finally, lack of investment funds in the other sectors of the economy leads to declining output of both industrial goods and services. As they fall, food and health services are reduced, decreasing life expectancy and raising average death rates.* (p. 168-69; emphasis added)

The peak of world population in the LTG scenario occurs in 2027 at 7.47 billion people – curve 1, Figure 4. Note well that the "lack of investment funds" is cited as one of the primary causes of collapse.

Bottom line: The tone of *Limits to Growth: The 30-Year Update* is cautiously optimistic. The authors maintained in 2002 that there was still time for the world to achieve sustainability, but the course of society would have to be quickly changed. However by 2022 it will be too late. The 20-year delay in moving toward sustainability sends the world "on a turbulent, and ultimately unsuccessful path. Policies that were once adequate are no longer sufficient."

2. The Olduvai Theory and World Population

> *[As a result of permanent blackouts of electric power] the industries of all civilized countries would stop working, so that, with millions unemployed and with a total cut in the production of goods,*

> *unprecedented and incurable misery would occur, killing perhaps three-quarters of the population, and leaving the rest in a deplorable state.* (Thirring, 1956, p. 135)

The data for testing OT Postulate 3 are not available at this writing. For the sake of discussion, however, I reserve Postulate 3 for later, and show that Postulate 4 (the Olduvai scenario for world population) is consistent with a growing number of autonomous studies.

The peak of world population in the OT scenario occurs in 2015 at 6.90 billion – curve 2, Figure 4. Notice that the OT scenario closely matches the LTG scenario up to 2012. Thereafter, however, the OT scenario diverges downward. Thus when the LTG scenario peaks in 2027 at 7.47 billion, the population in the Olduvai scenario has declined to 5.26 billion – the same value it had in 1990.

The differences increase over time. Namely: When the LTG scenario shows the world population at 6.45 billion in 2050, population in the OT scenario has fallen to 2.00 billion – the same value it had in 1925.

The differences between the LTG scenario and the OT scenario, I reason, occur mainly because the *Limits to Growth* model does not explicitly include world energy production, whereas the Olduvai Theory does (Duncan, 1989, 1993, 1996, 2000, 2001, 2003, 2004; Duncan & Youngquist, 1999).

Moreover, the Olduvai Theory specifies that permanent blackouts – each happening one-by-one, region-by-region, and spreading worldwide over time – will be the *proximate (direct, immediate)* cause of the collapse of industrial civilization. In contrast, the *Limits to Growth* model identifies many *ultimate (indirect, delayed)* causes of the collapse – especially the "lack of investment funds for industrial goods and services." Hence the LTG and OT scenarios are consistent and complementary.

The Olduvai scenario was neither first nor is it unique in projecting that world population could quickly decline to its pre-industrial level. Five examples follow.

In 1949 King Hubbert realized that the human population could collapse back to "the agrarian level of existence" ("Scenario III", discussed previously).

Austrian physicist Hans Thirring (1956) was, as far as I can tell, the first to recognize that the rapidly growing world population was increasingly vulnerable to the loss of electric power. His scenario (quoted above) suggests that permanent blackouts might kill "perhaps three-quarters of the [world's] population." Thus the widespread loss of electric power might cause the OT peak population of 6.90 billion in 2015 to fall to 1.73 billion in 2050.

According to Professor David Pimentel of Cornell University the world will have to adjust to lesser supplies of energy and food by a commensurate decrease in population. D. Pimentel and M. Pimentel (1996) state, "…the nations of the world must develop a plan to reduce the global population from near 6 billion to about 2 billion. If humans do not control their numbers, nature will."

Professor Richard Heinberg of the New College of California anticipates that oil and gas depletion will send prices of these fuels – along with the hydrocarbon-dependent fertilizers, pesticides, and herbicides – soaring. Hence without cheap energy, industrial agriculture will be able to feed only a fraction of the people it does now – perhaps less than two billion, roughly its pre-industrial level (reported by J. Attarian, 2003).

After reviewing an early draft of this paper, geologist Walter Youngquist (2004) wrote, "I doubt if population will be reduced to 2 billion or less by 2030 – you might want to modify that as the Third World will still have a lot living on a subsistence basis. I would move the 2 billion or so ultimate figure to year 2050 perhaps. By the way, the 2 billion is what others say is probably the limit in terms of a renewable natural resource economy – and the living is not likely to be as high as it is now."

To extend our survey, four widely circulated scenarios to 2050 tend to put the world population far above those mentioned above. Specifically, the US Census Bureau puts the world population in 2050 at 9.2 billion (USCB, 2004). In addition, the United Nations offers three population scenarios for 2050: 10.6 billion [high], 8.9 billion [medium], and 7.4 [low] (UN, 2004).

All population scenarios – we point up – are speculation. Only time will tell.

History gives no precedent for the collapse of industrial (electromagnetic) civilization, but the consequences of the policy of exponential brinkmanship are clear (White, 1943; Thirring, 1956;

Youngquist, 1997, 1999; Stanton, 2003; and Bartlett et al., 2004).

The overshoot and collapse of industrial civilization was assured once humanity became dependent on the rapid exploitation of nonrenewable resources on a finite planet. Moreover our insatiable appetite for electric power has accelerated the collapse and steepened the decline (Adams, 1907; Duncan, 2000, 2001).

The Olduvai Theory is extensively discussed on the worldwide web – pro, con, and more. Search for “olduvai theory” to access the various sites and forums.

Conclusions

The Olduvai Theory states that the life expectancy of industrial civilization is approximately 100 years: circa 1930-2030. Ackerman’s (“White’s”) Law defines it: *e = Energy/Population.* Four postulates follow:

1. The exponential growth of world energy production ended in 1970.
2. Average *e* will show no growth from 1979 to circa 2008.
3. The rate of change of *e* will go steeply negative circa 2008.
4. World population will decline proximate with *e.*

Henry Adams in 1893 envisioned that electric power would accelerate society into chaos and ruin. Frederick Ackerman in 1932 showed that social change could be quantified by *e.* King Hubbert graphed the shape of the *e* curve in 1949. Thus an Olduvai scenario existed before 1950.

None of the world’s five major sources of primary energy has grown exponentially since 1975 (Figure 1). World total energy production has not grown exponentially since 1970 (curve 1, Figure 2). *Postulate 1 is verified.*

The average rate of growth of world energy production per capita *(e)* was zero from 1979 to 2003 (curve 2, Figure 2). *Postulate 2 is confirmed through 2003.*

Seventy-four (74) out of the approximately 100 years of the Olduvai Theory are now history (Figure 3). All of the data needed to test it are freely available on the worldwide web and updated annually. Rigorous tests are welcome.

The Olduvai scenario for world population peaks at 6.9 billion circa 2015 (curve 2, Figure 4). Thereafter the population declines to 2.0 billion in 2050 (Postulate 4). A growing number of independent studies concur (see text). ■

ACKNOWLEDGMENTS

Walter Youngquist has bestowed wise guidance and much scientific information over many years. Robert Hickerson, Alistair McCrone, John Attarian, David Pimentel, Virginia Abernethy, and David Burghardt have helped out in many ways. Colin Campbell, Ali Samsam Bakhtiari, Alan Hammaker, and Francis de Winter have provided valuable perspectives on diverse subjects. Richard Pelto’s “Third Place Academy” has extended my horizons. Marvin Gregory has passed along a constant stream of useful information. Patrick McNally’s keen questions have been very helpful. Ronald Angel has stressed computational rigor. John Greer has fostered localized rural communities. The web sites of Jay Hanson, Ronald Swenson, and Tom Robertson have bought forth many useful discussions and suggestions from around the world.

ENDNOTES

1. Hydrocarbons, of course, are the crucial source of primary energy for industrial civilization – as it now exists. However *if* we had abundant and affordable electric power from other sources, *then* civilization – in some form and at some population level – could continue indefinitely sans hydrocarbons.

2. “We have, in the above generalizations *the* law of cultural evolution: *Culture develops when the amount of energy harnessed by man per capita per year is increased; or the efficiency of the technological means of putting this energy to work is increased; or, as both factors are simultaneously increased”* (White, 1943). But as far as I know no one has ever quantified how world total energy efficiency has changed over time.

3. Engineers usually represent electromagnetic energy as waves. Physicists often represent it as particles. A coherent theory is lacking.

4. The OT says that permanent blackouts will be the instantaneous (direct) cause of collapse of industrial civilization. In contrast, the deeper causality will be a complex matrix of delayed feedback interactions, including: depletion of nonrenewable resources, lack of capital and operational investment funds, soil erosion, declining industrial and agricultural production, Peak Oil, global warming, pollution, deforestation, falling aquifers, unemployment, resource wars, and pandemic diseases – to name just a few.

5. For exponential growth the year-on-year incremental changes must be positive and exponential; for exponential decline they must be negative and exponential.

6. The exponential doubling time ('DT' in years) is approximately equal to *69.3/PctG* where *'PctG'* is the average percent growth per year (Bartlett et al., 2004, p. 396).

7. One boe = 5.46 million Btu (heat value).

8. Worthy of note in Figure 3 is how clearly the plot of Ackerman's Law *(e)* reveals the Great Depression and World War II.

9. By definition, all scenario curves, dates, and scales are approximate.

10. System dynamics is a methodology for studying, testing, and managing complex, nonlinear, feedback systems, such as one finds in business and other social systems. See: www.albany.edu/cpr/sds.

DEFINITIONS

"Scenario" means an outline for any series of events – real, imagined, or tutorial. "Circa" indicates an approximate year. "Oil" means crude oil and natural gas liquids. "Total energy" means the world's five major sources of commercial energy combined: oil, natural gas, coal, hydroelectricity, and nuclear-electricity. "*e*" means energy production per capita. Energy "production" and "consumption" mean the same thing. (Although energy is neither produced nor consumed, these terms are common in the industry.) "%/y" means percent per year. "b" means barrels of oil. "boe" means barrels of oil equivalent. "G" means billion (10^9). "T" means trillion (10^{12}). "Industrial civilization," "electromagnetic civilization," and "modern civilization" all mean the same thing. "C.E." means Common Era; "B.C.E." means Before Common Era. "Brinkmanship" means the policy of pursuing a hazardous course to the brink of catastrophe.

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