# The Life-Expectancy of Industrial Civilization

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*To predict the future of a curve is to carry out a certain operation on its past.*
*Norbert Wiener, 1948*

**Abstract:** The life-expectancy of industrial civilization is defined. A feedback model of the human life-support system is used to study system controllability at the global level. The inadequacies of control, calculations based on energy-use data, and other considerations are used to theorize that the life-expectancy of industrial civilization is less than 100 years.

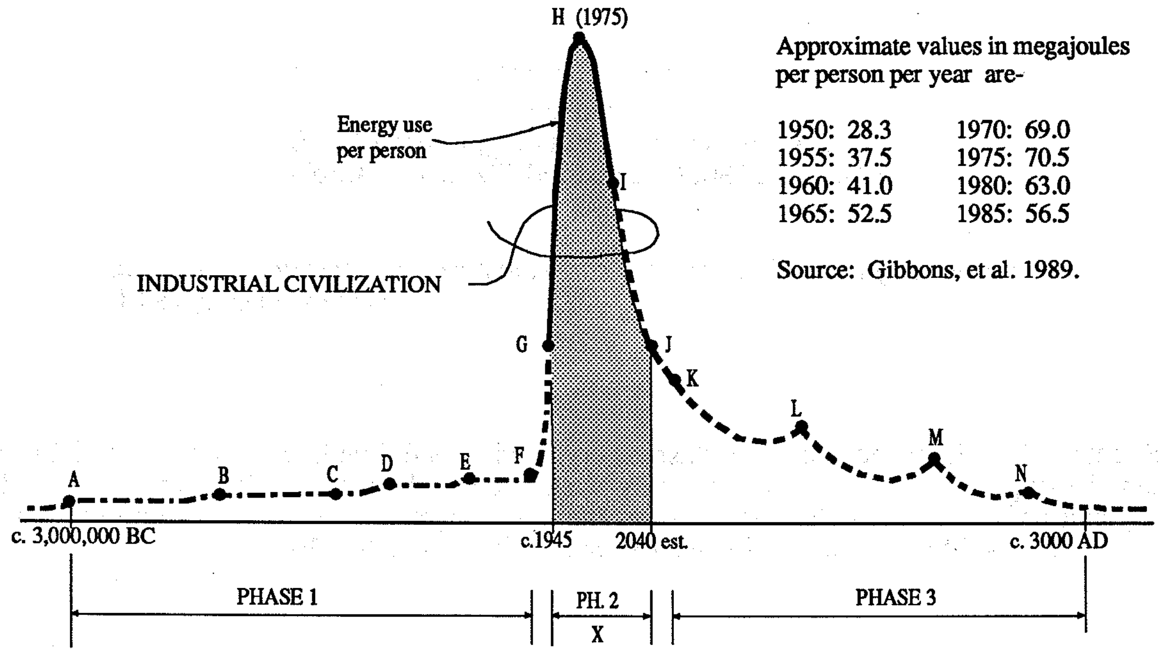
## Introduction

The goal of this essay is to estimate the life-expectancy of industrial civilization. This is accomplished by dividing the very long span of human history into three phases. The first, or pre-industrial phase begins at the dawn of human origins and lasts up to the stirrings of the Industrial Revolution. With the first phase as background, I focus on the second, or industrial phase of human history. A feedback model of the extant world system is used to check the essential requirements for system control at the global level. Next I present a quantitative definition of the life-expectancy of industrial civilization. Finally, energy-use data, system controllability, and other considerations are used to predict the life-expectancy of industrial civilization. The third, or de-industrial phase is mentioned only in passing.

## Energy Use Per Person - The Common Denominator

'If there's any one trend that has characterized the evolution of culture, it's probably an increasing ability to extract energy from nature. ... Indeed, an ability to harness larger energy sources is the hallmark of modern society' (Chaisson 1981, 250). By averaging this quantity on a per capita basis, we obtain a practical quantitative index: **energy use per person.** This index is comprehensive, describes all epochs of history, and cross-cuts all political, ethnic, religious and aesthetic boundaries. Further, energy use per person is well documented in recent decades, and it can be inferred with reasonable accuracy for earlier periods of human development. Therefore, energy use per person will be used herein to represent the gaping sweep of human history.

The general scheme of human history is divided into three phases: (1) ***pre-industrial,*** (2) ***industrial,*** and (3) ***de-industrial*** as shown in Figure 1 (Duncan 1989, 12-17). The *first,* or *pre-industrial phase* essentially was a very long period of economic equilibrium based on renewable natural resources (i.e. 'income'). It began in the Pliocene some three million years ago when our human-like ancestors first began making simple stone tools which, in turn, made possible greater energy use per person in the forms of food and material resources. Epic milestones serendipitously followed, including the controlled use of fire by about two million BC and, we may assume, teaching, a kinship-based social structure, and the use of language by one




1. PRE-INDUSTRIAL PHASE [c. 3,000,000 BC to 1765 AD]
   A = Tool making begins (c. 3,000,000 BC).
   B = Fire use begins (c. 2,000,000 BC).
   C = Cultural florescence (c. 30,000 BC).
   D = Neolithic Agricultural Revolution (c. 8000 BC).
   E = Roman Empire (peak c. 200 AD).
   F = Watt's steam engine, 1765.
   Interval F-G is a transitional period.

2. INDUSTRIAL PHASE [1945 to 2040 AD, estimated]
   G = Industrial Civilization is definded, post facto, to begin at 1945 when the leading edge value reached approximately 26.1 megajoules per person per year (i.e. 37% of the peak at 1975).
   H = Peak at 1975: 70.5 megajoules per person per year.
   I = Energy use per person declines (Holdren 1990) and the system is uncontrollable (Duncan 1991).
   J = Industrial Civilization is defined to end when energy use per person drops to 37% of the peak value, forecast to occur by 2040 AD. Life-expectancy (X) is predicted to be less than 100 years.
   Interval J-K is a transitional period.

3. DE-INDUSTRIAL PHASE [c. 2100 AD to indefinite future]
   L, M, & N = Recurring future attempts at industrialization fail (Duncan 1989). Other scenarios are possible.

**Figure 1. Major milestones and phases of human history**

million BC. Beautiful cave paintings and delicate miniature carvings in stone and bone mark a cultural florescence in central Europe at about 30,000 BC. This was followed in due time by the Neolithic Agricultural Revolution in the Near East at about 8,000 BC. Then in historical quick-time, Mesopotamian technological and social innovations spread to Greece and Rome by 200 AD, and following a respite of Dark Ages, the Industrial Revolution began to stir in western Europe. I mark the end of the pre-industrial phase in 1765, the year James Watt invented an efficient steam engine. However, despite considerable progress to this point, technology remained pre-industrial. Economic growth was limited by muscle power, and weak and inefficient machines. Global environmental impact stayed slight. Social control for the most part was adequately provided by feudal lords, monarchs and religious institutions.

The end of the pre-industrial phase was followed by a transitional period, commonly called the Industrial Revolution, when initially economic growth was limited only by the rate that capital could be accumulated for further growth. Industrializing nations 'eagerly' shifted from renewable to nonrenewable resources (i.e. 'capital') as the basis for economic growth. The transitional period is delimited by the years 1765 and 1945 (points ***F*** and ***G*** in Figure 1).

The *second,* or *industrial* phase of human history comprises the shaded central portion of Figure 1, including points ***G, H, I,*** and ***J.*** Based on a definition to be presented shortly, I mark the beginning of the industrial phase at 1945 (***G***), the year global average energy use reached approximately 26.1 megajoules per person per year. Then, only thirty years after it began, the peak of the second phase (***H***) was reached in 1975 at approximately 70.5 megajoules per person per year; then it abruptly went into steep decline, falling by 20 percent between 1975 and 1985 (Gibbons, et al. 1989, 88). The importance of the 1975 peak is ominous for its sheerness alone, but I believe its greater significance is that, despite heroic efforts to halt or slow the trend, energy use per person in developed countries is expected to continue to decline for at least the next several decades (Holdren 1990, 114).

Because the remainder of the industrial phase of human history lies in the future beyond 1991 (i.e. from points ***I*** to ***J*** in Figure 1), further consideration of the second phase will be deferred until after a discussion of a feedback model of the human life-support system.

A scenario of the *third,* or *de-industrial phase* is sketched in Figure 1, wherein global society approaches long-term stability at the subsistence level (Duncan 1989, 16 -17). This scenario was first brought to my attention by astronomer Fred Hoyle in the early 1960s. Also it is consistent with ideas of theoretical economists such as Adam Smith (1776, 59-66, 173-76) and Thomas Malthus (1798). However, because the circumstances of human society beyond the end of the second phase do not affect my thesis, I shall not entertain the third phase further in this essay.

## The Paradigm of Controllability - Is it Warranted?

Three computer-based simulation studies of the world system (i.e. Forrester 1971; Meadows, et al. 1972; Mesarovic & Pestel 1974) were widely discussed and debated during the 1970s. These studies focused on physical and material limits, and to a lesser degree on political, social and logistic limits. Human nature was recognized as a third limit, but not explicitly included in these pioneering models. These three types of limits are designated ***'outer limits'***, ***'inner limits'*** and ***'innermost limits'*** respectively (A. King, in Pestel 1989, 9). The innermost limits are now better understood, but still remain a quandary. 'Some of the toughest issues facing us ... are the consequences of large-scale cultural patterns, the summed effects of millions of people making individual decisions. Engineering communities have become painfully aware that such phrases as the "tragedy of the commons" and the "tyranny of small decisions" ... are accurate descriptions of reality, a reality that is difficult to alter' (Ausubel, et al. 1989, 19). Below in this section, I shall describe a four-sector feedback model that I developed to reveal the innermost driving forces, limits and feedback loops in the world system, and then proceed to the related question of system controllability (Duncan 1991).

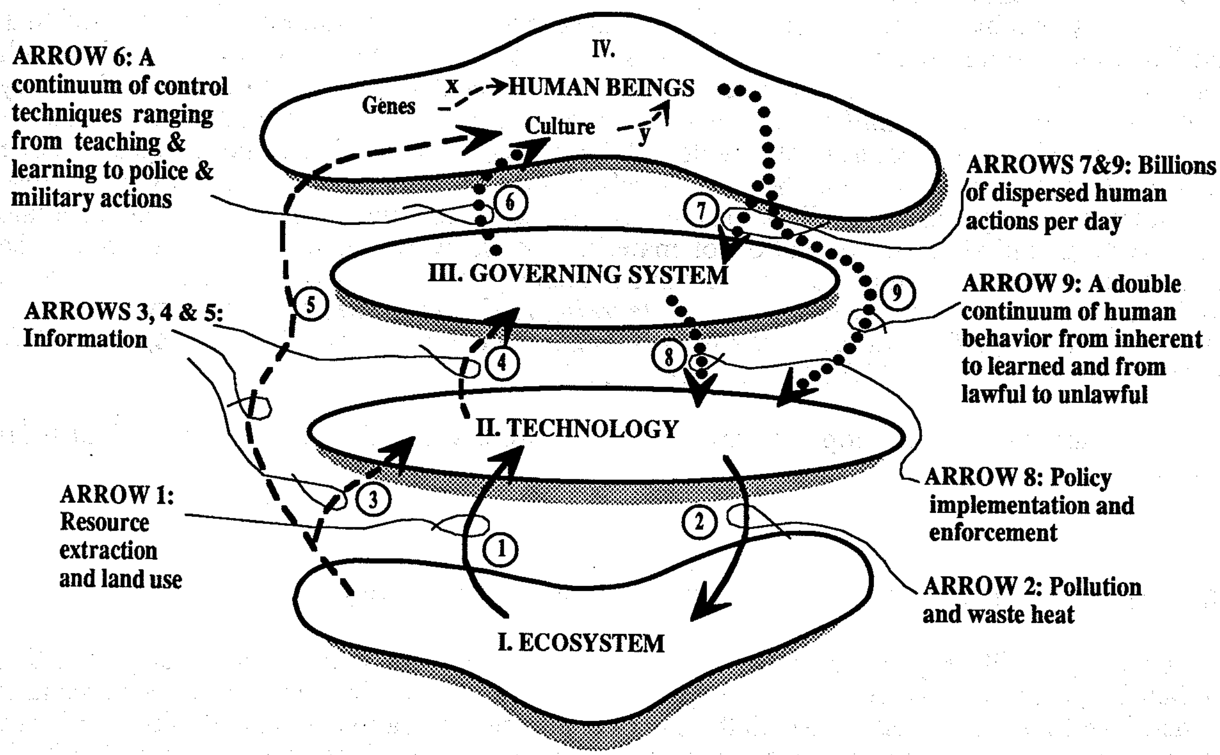
An important three-sector feedback model of the human life-support system was developed some years ago by H.E. Koenig, et al. (1975) to explore alternative policies for 'a more balanced trajectory of development'. While re-reading this paper in light of recent developments in evolutionary biology, I sensed that a fourth sector had to be added to disclose the innermost interactions in the system: the driving forces of individual human behavior. I designated the new sector ***'human beings'*** (Duncan 1989, 16). To check my intuition, I went back to the dawn of life on earth and traced the evolution of culture forward to social primates at 20 million years ago, then to tribal hominids at one million years ago, and finally to the present human life-support system (Duncan 1991). This evolutionary approach to model construction confirmed that the fourth sector was indeed necessary to expose the innermost structure of the model. Briefly put, since individual human behavior has both ***hereditary*** and ***learned*** components, each component must be separately represented in the model, then globally summed. The resulting model is shown in Figure 2, where ***'genes'*** in Sector IV represent genetic information and ***'culture'*** represents learned information.

On a continuum ranging from *pure inherent* to *pure learned*, the inherent component of human behavior is represented by arrow ***x*** and the learned component by arrow ***y*** in Figure 2. But note carefully that, because the human gene pool is assumed to be constant in the time-frame of interest in this study, ***genes*** are shown as an 'open loop', without causal input. Only ***culture*** (i.e. extragenetic learning) appears directly in feedback loops. Specifically, the cultural component ***y*** appears in interaction linkage ***6-y-7***, and also in linkage ***6-y-9***. Overall control of the world system is possible only if causal interaction ***6*** ('a continuum of control techniques ranging from teaching & learning to police & military actions') acting through ***y*** can dominate the gene-based dispositions acting through ***x***. Some renowned writers have been optimistic about this prospect. 'What is congenital in human nature has probably changed little during hundreds of thousands of years, but what is congenital is only a small part of the mental structure of a modern human being. ... Our less orderly impulses are dangerous only when they are denied or misunderstood. When this mistake is avoided, the problem of fitting them into a good social system can be solved by the help of intelligence and goodwill' (Russell 1949). My viewpoint is more sober. 'Open link ***x*** in the model represents a vast number of strong biologically-based human dispositions that simply overwhelm the relatively weak cultural influence represented by link ***6-y***' (Duncan 1989).

I tested the paradigm of controllability of the world system at the global level by checking the requirements for control against the properties of the four-sector model of the human life-support system. For brevity, the world governing system is called *'the governor'* and the human life-support system is simply called *'the system'*. A short summary follows. The nine requirements tested were:

(1) The governor must be *unique* and *comprehensive.*
(2) The governor must continuously *monitor* the major variables in the system.
(3) A *set-point* value must be defined for each major variable in the system.
(4) The *response time* of the governor must be significantly less than that of the system.
(5) The governor must have sufficient *activation strength.*
(6) Set-point values must be *apportioned* to lower levels of the system.
(7) The system *driving function* must be finite.
(8) A general *philosophy of control* must be imposed or agreed upon.
(9) *Cultural influence* must dominate genetic influence in human behavior.

'The nine fundamental requirements were investigated and each was found inadequate or entirely lacking in the model, indicating that the world system is highly unstable, and structurally and functionally uncontrollable. Several deep-seated problems were identified that indicate, if the model is correct, it will prove practically impossible to govern a world society' (Duncan 1991).




SECTOR I. ECOSYSTEM
This is the earth's natural environment comprising all land, water, air, energy & material resources, plants and animals.

SECTOR II. TECHNOLOGY
This is the human industrial and consumption system comprising all technology used for agriculture, physical production, transportation, et cetra.

SECTOR III. GOVERNING SYSTEM
This is the social regulatory system comprising all human institutions and processes: economic, financial, governmental, judicial, military, educational, religious, et cetra.

SECTOR IV. HUMAN BEINGS
This is the global population comprising billions of individual human beings. Genes process hereditary information. Brains process cultural information.

| | |
|---|---|
| SOLID ARROW | = Materials & energy flow |
| DASHED ARROW | = Information flow |
| DOTTED ARROW | = Human behavior or institutional action |
| ARROW x | = Genetic influence |
| ARROW y | = Cultural influence |

Figure 2. Four-sector feedback model of the human life-support system: 1991

At the beginning of this section, I mentioned three simulation studies of the world system that received wide attention in the 1970s. The authors of these studies correctly recognized the need to control the system by *cultural means* (i.e. by *teaching* and *learning*). Likewise they realized that conflict would result if institutions imposed laws, penalties, regulations, et cetera that clashed with 'congenital human nature'. Too I believe the authors questioned the paradigm of controllability by injecting sets of *socially and politically unacceptable policies* into various simulation runs to force the models into a 'controllable mode'. 'Many people will think that the changes we have introduced into the model to avoid the growth-and-collapse behavior mode are not only impossible, but unpleasant, dangerous, even disastrous in themselves. Such policies as reducing the birth rate and diverting capital from production of material goods, by whatever means they might be implemented, seem unnatural and unimaginable ... Achieving a self-imposed limitation to growth would require much effort. *It would involve learning to do many things in new ways. It would tax the ingenuity, the flexibility, and the self-discipline of the human race'* (Meadows, et al. 1972, quoted in Pestel 1989, 179-180). The emphasis is mine.

I next turn to the main topic of this essay, to estimate the life-expectancy of industrial civilization.

## The Life-Expectancy of Industrial Civilization - Is X < 100?

Pondering the life-expectancy of 'advanced' civilization has been in the air for a long time. The brilliant English geneticist J.B.S. Haldane (1927, 61) wrote a clever, half tongue-in-cheek scenario entitled *'The Last Judgement'* in which the end of civilization on earth came in 39 million AD as a result of intense heat and gravitational forces caused by the moon's close approach to the earth. In the early 1960s, astronomer Frank Drake and colleagues tentatively assumed that the average longevity of an advanced technological civilization in the Galaxy is one million years. Measured in terms of *industrial output per capita,* the Meadows, et al. (1972, reproduced in Pestel 1989, 167) 'standard run' simulation indicated a life-expectancy of only about 100 years, and as I recall, the behavior of the Forrester (1971), and Mesarovic and Pestel (1974) models was similar. Paleoanthropologist Richard Leakey and biochemist Roger Lewin (1977, 238) predicted that, because the material affluence enjoyed by technologically advanced nations was so destructive of the planet's natural resources, even the 1977 global population of four billion could not be sustained longer than a hundred years. Systems theorist Ervin Laszlo (1987, 123) reflected about the grand situation. 'Could it be that the reason we have been unable to make contact with extraterrestrial civilizations is that their life-expectancy is extremely short? This answer cannot be proven, but it also cannot be ruled out.' To facilitate discussion on a standard basis, I shall now offer two definitions and one theory.

- o In terms of a pulse waveform, the *life-span of industrial civilization* (*S*) is the duration in years between the point in time where the value of the leading edge of the waveform of energy use per person increases to 37 percent of its peak value and the corresponding point where the lagging edge decreases to the same value.

- o The *life-expectancy of industrial civilization (X)* is the predicted life-span of global industrial civilization.

- o ***X*** is less than one-hundred years: ***X < 100.***

The definition of ***S*** is based on the standard practice of defining a single pulse waveform in terms of three critical points: the peak value, and the leading and lagging (i.e. increasing and decreasing) 1/e points. Although it may prove to be only a local maximum, I believe the global peak (point ***H*** in Figure 1) occurred in 1975 at a value of approximately 70.5 megajoules per person per year. Data from Gibbons, et al. (1989, 88) indicates that the leading 1/e point occurred at about the year 1945, which I have taken as the starting year of the industrial phase (point ***G*** in Figure 1). However, the importance of the 'pulse' theory of industrial civilization is directly related to the occurrence of the lagging 1/e point (point ***J*** in Figure 1). If that point is thousands or millions of years distant, then further consideration of the theory is academic. However, if it is only a hundred years or less, then the theory has urgent implications.

Besides the problems of system control already discussed, there are three other reasons why the end of the second phase is likely to occur within the next few generations. The *first reason* is the result of a simple calculation tempered by judgement, as follows. Recall that the curve of energy use per person remained relatively flat for millions of years until, at about 1765, an explosive rate of energy use began that continued up to the peak at 1975. Then suddenly the long trend reversed. Between 1975 and 1985 the global average rate of energy use per person declined at a rate of 1.4 megajoules per person per year. If that rate were to continue indefinitely after 1985, then the critical point on the declining edge would occur at 2007 AD. However, rather than a linear rate of decrease, I assume that *exponential smoothing* will slow the rate of decline so that the lagging 1/e (point ***J*** in Figure 1) will not be reached until 55 years after 1985 (i.e. at 2040 AD, or 95 years after the start of the industrial phase).

The *second reason* stems from what I have seen of the people and conditions in some fifty diverse countries over the past forty years. Interleaved with fond memories of the still great beauty of the natural world, the piteous scenes of growing destitution and squalor among vast populations in what are patronizingly called 'the developing countries' leads me to conclude there is a vanishingly small chance that the downward trend of energy use per person can be halted or reversed before the value falls to 37 percent of the 1975 peak. Anybody who seriously observes the plight of the growing masses in countries such as Peru, Equador, Brazil, Sudan, Ethopia, Tanzania, Pakistan, India, Bangladesh, China, and Indonesia will agree with this conclusion or be obliged to explain how the decline can be halted or reversed in less than two generations.

The *third reason* is both personal and universal. It derives from the basic motives I sense in myself: *the innermost forces* that drive my behavior such as self-centeredness, immediacy, growth-orientation, and factiousness (Duncan 1989, 14-16). Here I refer to the powerful gene-based behavioral patterns (represented by arrow ***x*** in Figure 2) that simply overpower the weak and inconsistent culturally-based behavioral patterns (arrow ***y***). I believe these deep and universal drives, fixed in the human genome by natural selection over thousands of Pleistocene generations, virtually ensure the end of industrial civilization by 2040 AD.

In concluding this section, I note that the theory (***X < 100***) satisfies certain criteria which, to borrow the flowing words of J.B.S. Haldane (1927, 64-66), 'every attempt, however fantastic, to forecast the future should satisfy'.

- *In the first place, the future will not be as we should wish it.*

- *The theory should use a proper time-scale.* Human cultural evolution was traced back millions of years to reveal the innermost driving forces, limits, and feedback loops in the world system.

- *The theory should satisfy the existence theorem.* We know that a solution exists and the value of ***X*** is finite because at some distant future time the sun and earth will die.

- *The theory should be falsifiable.* It can be rejected by empirical data in less than 54 years.

## Summary and Conclusion

The goal of this essay was to estimate the life-expectancy of industrial civilization. To accomplish this, human history was divided into three phases: pre-industrial, industrial, and de-industrial. Each phase was described in terms of energy use per person. The first phase began millions of years ago when early man began making tools, and it continued through the yawning millenia that saw the controlled use of fire, beginnings of language, and the Neolithic Agricultural Revolution. In due time, this was followed by a transitional period commonly known as the Industrial Revolution.

The second, or industrial phase was the focus of this study. By definition it began in the mid-1940s when average energy use per person reached a critical point and, from there, continued up to an Everest-like peak in the mid-1970s. Then suddenly it went into a steep decline that, despite mighty efforts to halt or slow it, continues to date. I deferred discussion of the third critical point in the industrial phase, pending presentation of additional topics.

Considerations of human cultural evolution during the countless generations of the first, or pre-industrial phase provided the basis for a four-sector feedback model of the present human life-support system. This model was built to expose the major interactions, limits and feedback loops in the world system, especially the driving forces of human behavior. The model was then used to check nine prerequisites for system control. Each requirement was found to be either inadequate or entirely lacking in the model indicating that, if the model is correct, the world system is highly unstable and structurally and functionally uncontrollable.

Based on average energy use per person, the life-expectancy of industrial civilization was defined in terms of a pulse waveform having three critical points: a point on the leading edge, the peak point, and a point on the lagging edge. Using data from the years 1950 through 1985, I assumed that the peak at 1975 was the global peak (i.e. the second critical point). The data indicated that the first critical point occurred at about 1945, which marked the start of the industrial phase of human history. A simple calculation based on average energy use since 1975, along with the inadequacy of system control and other considerations, indicated that the lagging (or third) critical point is likely to be reached before the mid-point of the next century. The study concluded that the life-expectancy of industrial civilization is less than 100 years.

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