The Ultimate Dilemma for Artificial Capitals:

Ever scarcer natural resources claim

Ever larger artificial capital

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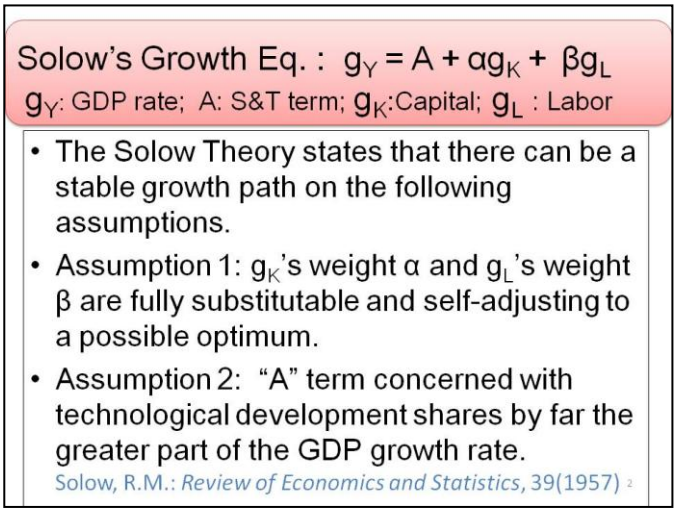
Slide 2



The lead line of this slide shows Robert Solow's Growth Equation, where g_Y is GDP growth rate, A is Science & Technology contribution, g_K is Capital growth rate; g_L is Labor growth rate.

His theory states that there can be a stable growth path on the following assumptions.

Assumption 1: g_K's weight α and g_L's weight β are fully substitutable and self-adjusting to a possible optimum.

Assumption 2: "A" term concerned with technological development shares by far the greater part of the GDP growth rate.

Solow, Robert M.: *Review of Economics and Statistics*, 39(1957): 312-20

These assumptions are of a purely mathematical conditionality. So there is no guaranty that K&L should be substitutable for their full range.
Also, technology depends heavily on the quantity and the quality of natural resources. And it is subject to the laws of science, such as energy conservation and entropic irreversibility.

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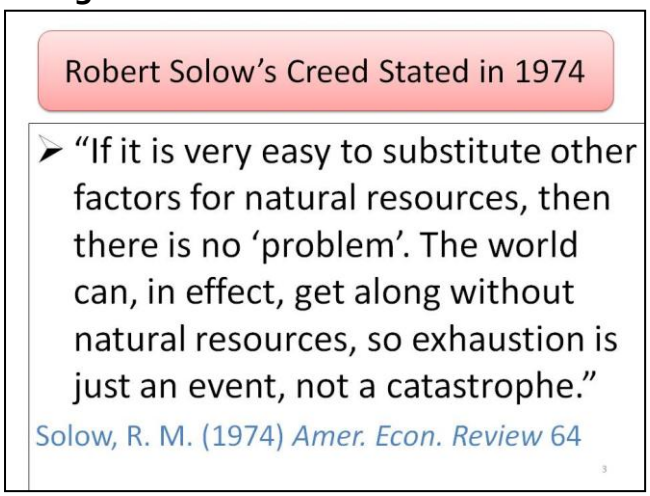

In 1972, *The Limits To Growth* (LTG, 1972) raised a pivotal problem that the present world economy will inevitably confront dual constraints of natural resource depletion and the environmental degradation.
Then First Oil Shock took place in 1973 as if to confirm the alarm brought forth by the LTG.
However, growth-oriented (majority) economists tried, almost indignantly, to refute the framework set up by the LTG.
For example Solow (1974) announced his conviction that the growth could retain itself intact despite of any natural resource decline. In fact he said "If it is very easy to substitute other factors for natural resources, then there is no 'problem'. The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe." Solow, Robert M.(1974) American Economic Review 64.
Solow's 1974 paper was written in the last afterglow of the age of cheap oil and technological progress in energy conversion, material processing, and informational technologies.
Solow's reconfirmation of the growth theory was based on mathematical 'if …then…'assumption and not on factual 'because…therefore…' circumstances.
So his dogma had no real ground to stand on.
However, his neo-classical conviction was not seriously tested because there appeared the decades of oil glut since 1980.

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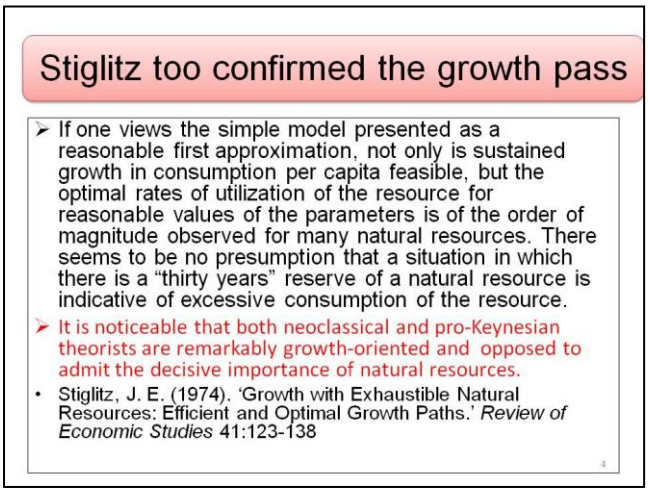
Stiglitz (1974) also gave a similar comment against the LTG.



It is noticeable that both neoclassical and pro-Keynesian theorists are remarkably growth-oriented and opposed to admit the decisive importance of natural resources. Growth-oriented theories, however, remained untested during the 1970s of the Oil Shock period because the 1980s and 1990s were the age of Oil Glut except during the US-Iraqi wars. And the presupposed 'substitutability' hypothesis between the natural and artificial capitals was exempted of a decisive test.

Stiglitz, J. E. (1974). 'Growth with Exhaustible Natural Resources: Efficient and Optimal Growth Paths.' *Review of Economic Studies* 41 (symposium on the Economics of Exhaustible Resources): 123-138

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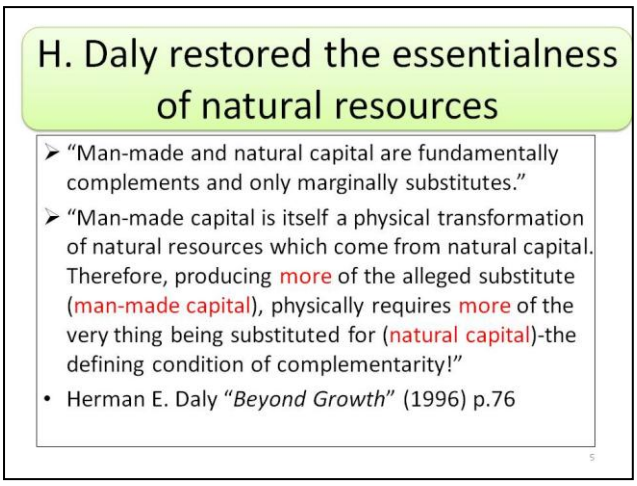

H. Daly restored the essential importance of natural resources "Man-made and natural capitals are fundamentally complements and only marginally substitutes." "Man-made capital is itself a physical transformation of natural resources which come from natural capital. Therefore, producing more of the alleged substitute (man-made capital), physically requires more of the very thing being substituted for (natural capital)-the defining condition of complementarity!"

Daly, Herman E.: "*Beyond Growth*" Bacon Press (1996), Boston Ms., p.76

We can reinforce Daly's theory: If we consider that resources will suffer degradation, then the simple metabolic replacement will require more and more man-maid capital and natural resources to make them, needless to speak of growth.

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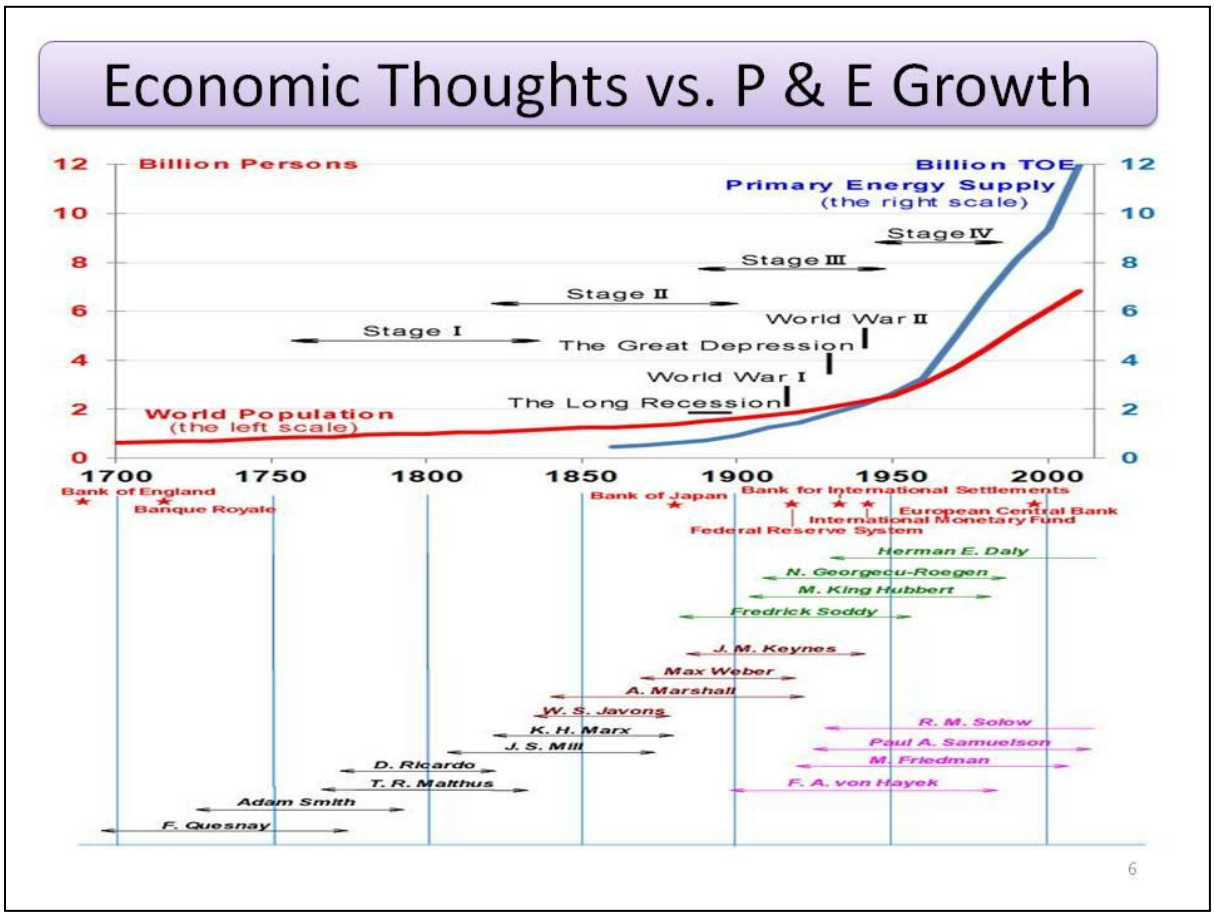

This slide shows an historical transition of the world population and the world PES. Also, the life spans of major economic theorists are depicted in the lower half.
The both curves represent a closely similar trend. The basic tone is a fairly monotonous expansion. Wars, business cycles, oil shocks have been masked readily in the time average.

There is a pivotal turning point around 1950, which triggered an upturn to the age of almost exponential growths.
Before 1950 the world had been on the coal-based economy: it had been the age of solid fuels, labor-intensive, low-calorie, and unfit for continuous transport or processing.
Around 1960 the world reached the oil-based economy: it opened the age of fluid fuels, labor-saving, high-calorie, and very fit for continuous transport or processing.
Since 1960, the world economy has begun to acceleratedly pump up oils and gases that enabled and supported the rapid growths of the World Industrial Production

and the world population.

Economics theorists depicted three/four decades of the above-charted history by using their own favorite colors. Their pictures are different in colors but similar in shape, i.e. qualitatively various but quantitatively analogous.

What we should confirm here is that the real motive force of growth is nothing but PES expansion. Technology is not the driver but the driven: it simply works as an energy converter (i.e.as an energy consumer), nothing more/ nothing less.

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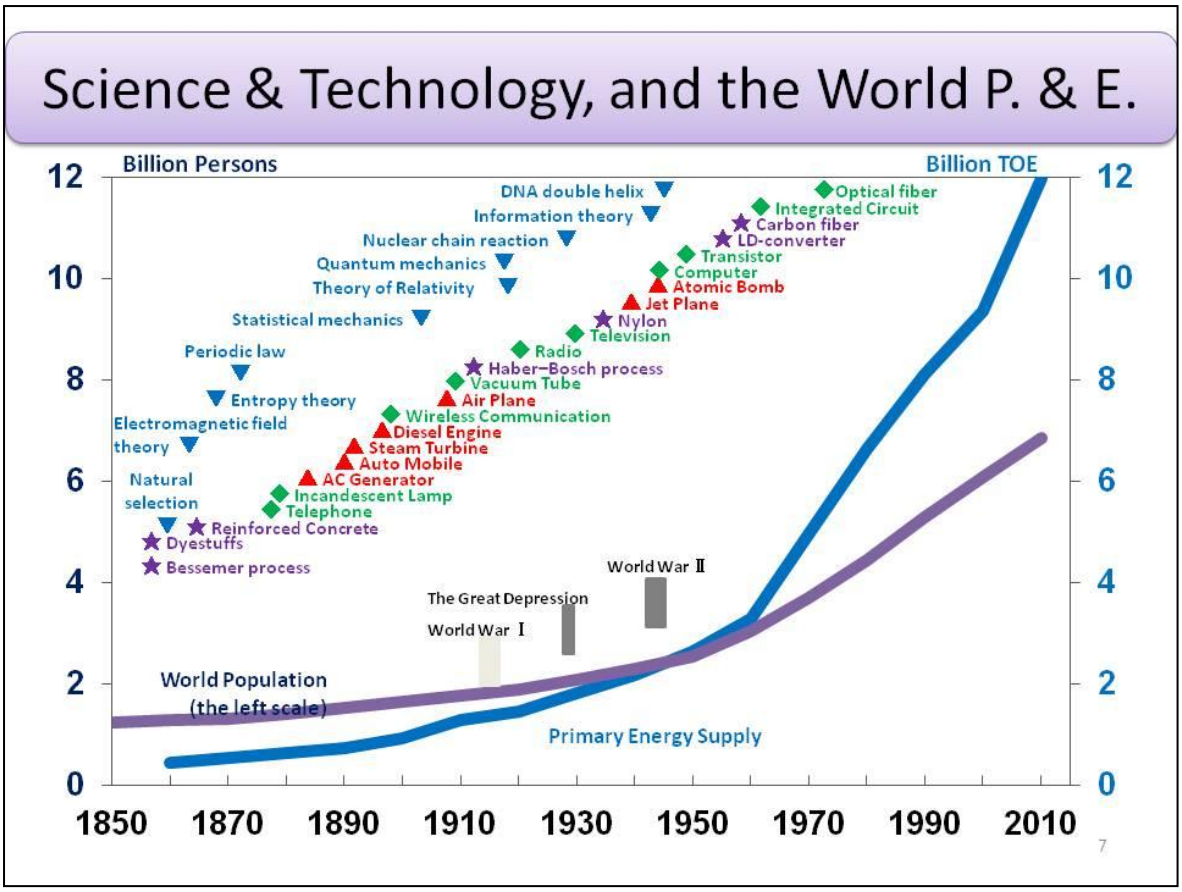

This chart summarizes all major scientific discoveries and technological inventions, along with the PES and the population trends.

The former are marked with blue triangles, and the latter are represented by sector: Energy engineering is denoted by red triangles; material processing, by violet stars; and information technology, by green squares;

It is roughly apparent that major scientific achievements have been accomplished before 1960 and that major technological progresses, by early 1970s.

In fact, China, the largest growth engine, since the late 1980s has not produced, or utilized any new technology. They single-mindedly borrowed and borrowed extant technologies and made full use of their abundant cheap labor and eagerly procured energy.
In contrast, Japan, one of major exporters of extant technologies, simply suffered an ever-lasting hollowing out of industry, without being able to replenish its industry with any novel technologies.
The China Model may pervade into Vietnam, Burma, India, or into other continents. However, there seems to appear no promising technological seeds, and if any, there seems no part for them to play.
No one can compete against an economy well equipped with a set of "cheap labor and default technology".

Most economists have always and unanimously been regarding technological innovations as Deus ex Machina, or a cure-all Elixir for economic growths. That idea had become invalid about three decades ago.

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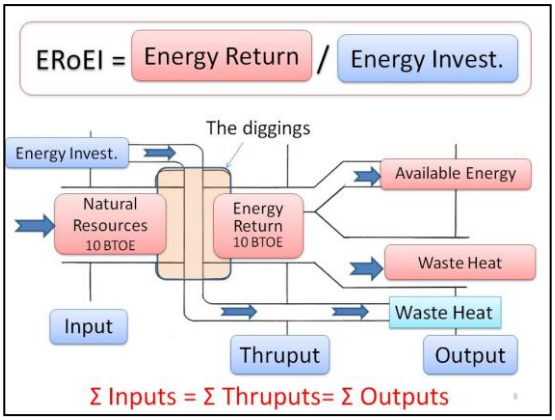

People often talk of the growth engines of the world economy such as Japan in 1960s and China in 1990s and 2000s. However, engines themselves cannot drive anything: what really turns the wheel is oil or other fuels. It is the fuels they procured that really operated Japan's or China's economy.
This explains why and how peak-oil will strangle the world economy.
The 'peak-oil' theory does not mean actual depletion of oils but describes degradation of proven fuel reserves. But what does this degradation mean?
Here let us just look back on the definition of ERoEI.
Degradation of natural resources calls for ever-increasing Energy Investment for the extraction. Besides, facilities (man-maid capital) for resource extraction will become more and more costly. This directly lowers ERoEI because of increasing denominator. And besides, the economy has to deduct a larger part of Available

Energy to feed the EI for further operation. Thus a kind of negative feedback in energy extraction will set in.

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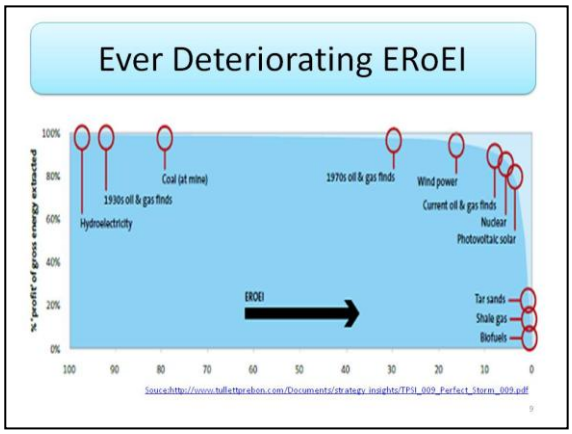

This chart shows the theoretical relation between the ERoEI and resources degradation studied by Tim Morgan(2013).

For mineral fuels, the grade of resources can be defined by its thermodynamic purity (exergy content).

This 'grade' of various fuel resources are denoted on the y scale.

The x or lateral axis represents the value of ERoEI in decreasing order:

the left end corresponds to 100% ER or a fully spontaneous emission of fuels (though a recovery operation will be necessary).

Remarkably the relation is abnormally non-linear and most renewable energies and nuclear energy have low ERoEI

despite their resource grade is fairly high. Thus there is a steep ER 'cliff', or a sudden and precipitous decline in ER.

Life After Growth. How the global economy really works - and why 200 years of growth are over. By: *Tim Morgan* Format(s): Hardback ISBN(s): 9780857193391 Published: 18 November 2013 Edition: 1st. SKU(s): 873332.

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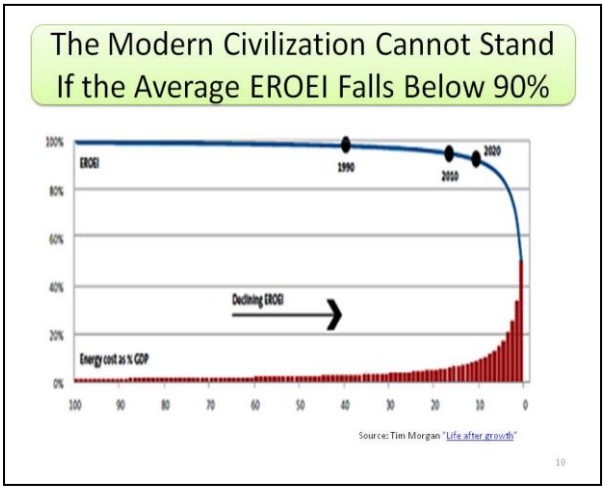

This slide shows the cost increase (the brown bars) and the return ratio decline (the blue line) of the average primary energy. This chart represents a time development of the two data. Yet it also shows the ER 'cliff' and has a striking resemblance to the former chart.

With the development of time, our economy gradually run out of high

grade resources and come to depend on lower grade resources, which in turn theoretically lowers ERoEI. This is why the two charts fall in a closely similar structure.
Vertical scale shows corresponding 'profit' which is equal to <acquired energy (in %) – invested energy (in &)>. This ERoEI deterioration directly means that primary energy extraction will need ever increasing reparation of artificial capitals.
The Modern Civilization will not be able to stand if the Average EROEI falls below 90%: therefore the world economy will not be able to survive the ER ratio 'cliff'
Life After Growth. How the global economy really works - and why 200 years of growth are over. By: *Tim Morgan* Format(s): op. cit. p.66.

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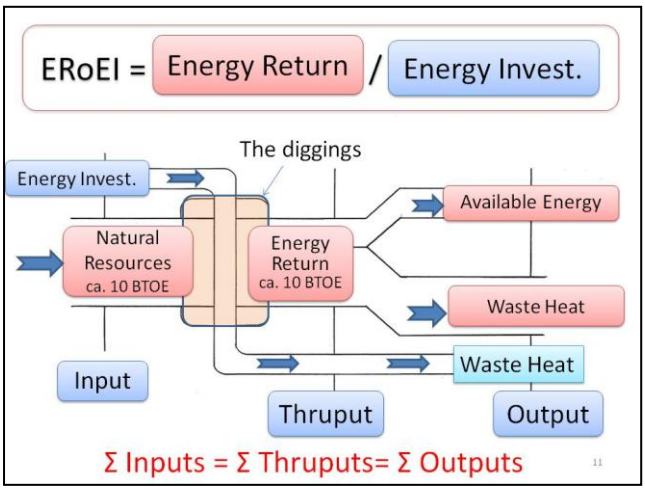

In conclusion, the industrial economy is essentially vulnerable to the decline of ERoEI. When ERoEI=90% or ER/EI=9, they may seem sufficiently high. This results in that, however, *Available E*/EI is only 3, far smaller than 9, because the available energy ratio is 1/3.
And we have to deduct, from this scarce Available Energy, an increasing part for the EI and the extraction facilities. Thus the energy industry comes to bear the more *in-house energy consumption* and so cannot help providing *the less Available Energy* to other industries.

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