The International Productivity Problem,
The Energy Transition, and
Globalization, Going Forward

Summary: The current worldwide slowdown in productivity gains may reflect a combination of decreasing energy returns on energy investments in fossil fuels, and limitations on contributions to system-wide productivity gains in the early stages of development of renewable energy replacements. A review of the development process in terms of non-equilibrium thermodynamics concepts is in order. The stresses of the upcoming major worldwide energy transitions, accompanied by climate change protections, are likely severely to test national and international coordination systems, and the globalization construct.

1. The Current Productivity Problem

Numerous publications have been reporting that rates of productivity gain have been declining in recent decades across much of 'developed world', and, from higher levels, in many 'developing' economies. A recent publication of the highly respected Brookings Institution probes this issue

Perhaps the most recent and striking analyses have been done by the National Conference Board in the United States, showing almost imperceptible gains, and some losses, in the most developed economies in the world See for update

The Conference Board analysis focuses in part on 'total factor productivity' -- a measure of the extent to which the organization of 'capital' and 'labor' adds to the quantities expressed by those inputs in increasing the total output per unit of labor. The Conference Board's summation on this is as follows

Zero or even negative total factor productivity growth suggests that improvements in the efficiency by which labor and capital are used have stalled ... Ultimately declining TFP prevents companies from improving their competitiveness and profitability, and threatens the ability of countries to maintain or better people's living standards.

As of this writing, the International Monetary Fund reports low growth prospects across a broad range of economies, and some difficulty in identifying why this should be so.[1]

[1] "The causes of and interactions between these various (demographic) forces are complex and not well understood. However, what is clear is that these trends are coinciding with a well-documented decline in potential growth … that is being mirrored across a range of advanced and emerging economies"

If these trends continue,[2] one implication could be that the current gaps between developed nation productivity per person and less developed nations per person productivity will narrow. If the current productivity leaders do not find means of additional productivity growth, this would seem likely to lead to greater competition between the current global economic leaders, and their populations, and the less developed nations, as to internationally traded goods and services.

2. Current Related Financial Policy Actions

As this has occurred, the institutions charged with coordinating national and global financial activities (to the extent determinable and manageable) have undertaken attempts to encourage a resumption of 'growth' (which has typically been measured within States as gross domestic product or gross national product). The conceptual basis for such measures seems to assume that growth rates should be those typical of the late 19th and the 20th centuries.

In much of the 'policy' parlance, national governments have considered that they had two principal levers for trying to get economic activity back up to accustomed and/or targeted levels, termed 'monetary' and 'fiscal'.

As to 'fiscal' action, the national government is assumed to be able to authorize economic activity directly, and to issue whatever monetary instruments, or forms, will be accepted in the markets supplying goods and services.

Typically, the 'fiscal stimulus' is of a quantity which would not be funded by current taxation by the issuing body, and thus there is implied either a rise in taxation (which many would suggest would offset the stimulus by taking monetary units involved out of general circulation), or issuance of 'debt' -- i.e. promises to issue monetary units in the future.

This would have implications as to maintaining equivalence between the resource value (which I will soon equate with 'energy') and monetary units over time, and between allocations between government and nongovernment systems over time, briefly suggested in the margin.[3]

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[2] One might consider two scenarios -- a global convergence of productivity and welfare levels, or a stable distribution of relative productivities and welfare levels, perhaps on a log normal curve. Log normal curves are ubiquitous in the Universe. But any given entity may not be guaranteed its relative standing on such a curve.

[3] If these promises to emit monetary units were to be made good by future taxation, the transaction would amount to a stimulus to activity in a current time period in the hopes of reaping units of exchange, made good (at an assumed equivalence between 'goods and services' and monetary units over time) by taxing expected increased levels of activity at later periods, with no resultant change in the relative proportions of taxation and economic activity over time. If the expectation were that there were no resultant increase in taxable activity in the future, the exchange would be for less pain now for more pain (decrease in expectable activity) later. Not usually attractive, if understood. If the expectation were that for reasons not solely involved in this transaction, the monetary unit used and to be used were expected to claim less resource in the future (e.g. there is expected 'inflation'), then the governing unit would have achieved a

There seems to be more attention given to 'monetary' policy, typically managed by central banks, and institutions to coordinate the policies of national central banks (to the extent units of exchange, which we call money, are and can be managed).

National central banks have tended to try to stimulate economic activity by actions which make monetary units more amply available for national and international transactions. A part of this strategy is actions to lower the interest rates which generally apply in such transactions. This is thought likely to increase the levels of activity in investing in the production of goods and services (and in consumer purchases) by reducing the levels of yield needed over time from such activities to attract the 'capital' which will enable such activities. Recently, central banks have developed another monetary policy tool -- so called 'quantitative easing', through the purchase of securities, or debt, from banks, with electronic cash. I will not discuss this technique in detail here, focusing instead on the broader theme of lowering prevailing interest rates.

At this time, most of the institutions with central bank functions, in the 'developed' economies, have been targeting very low interest rates for an extended period of time. One gets the impression they are gingerly feeling their way forward, paying very close attention to if, when, and where economic growth rates may regain the levels more typical of decades in the middle and later stages of the 20th century.

As inquiries into the sources of productivity gains, and thus economic and welfare gains, in Western and global societies have proceeded, yielding many useful insights, there have been at least two other parallel discussions with implications for economic activities. This article suggests that these inquiries are particularly significant at this time.

3. Current Awareness of a Need for an Energy Source Transition

It is generally understood that the enormous gains in human populations and activities have come from exploiting the 'energy' in fossil fuel, or earth-stockpiled, hydrocarbons. Discussions of productivity gains over time -- generally the 19th and 20th centuries -- seem to have assumed that the fossil fuel flows supporting such gains will be available at the same levels and costs as have been the case in these last two centuries. But looking ahead a century or two, this cannot continue to be taken as a given.

First, the prospective climate effects of combusting these hydrocarbons, to get the energy yield, has spurred a global search to replace these energy sources.

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sort of arbitrage at the cost, if there were assumed to be one, of reducing future obligations to pay for current uses of resources -- in effect a systemically discounted set of future obligations.

At the same time, the net energy yields from mining these hydrocarbons, taking into account all energy costs, have tended to decrease. And, though there are large quantities of hydrocarbons in the accessible ecosphere, the limits of the most energy rich hydrocarbon deposits seem visible, given current and prospective consumption rates.

This leads to an expectation that these yields will decrease, in total volume, in the coming century or two.

The efforts to develop 'renewable' or 'sustainable' energy sources have led to a focus on a key measure -- the energy returns on energy invested (EREOI) in such renewable technologies. Those tracking the development of renewables are keenly interested in when they will meet or exceed the EROEI of fossil fuels, and whether, and when, such energy yields will be sufficient to support a high energy industrial civilization in the future.

This has led, or this author suggests should lead, to shifting the conceptual center of discussion as to economic (and social) activity to the energy flow factors which enable such activity.

4. The Rise of Academic Understandings of 'Non Equilibrium Thermodynamics'

This dovetails into a stream of academic thought which has steadily expanded in recent decades, often termed 'non equilibrium thermodynamics'.

The foundations of this thought go back at least as far as Heraclitus of Ephesus, born about 560 BC, who saw all things as process. There is still a subsection of philosophy known as process philosophy.

However, in recent decades astronomers, physicists and others have expanded, elaborated, and measured these concepts in universally applicable ways. This article suggests that it is time to introduce thinking of this sort into current economics, and aspects of political economy such as fiscal and monetary policy.

Re-casting the productivity issues in thermodynamic terms may help answer a key question.

On the one hand, some suggest that the current slowdown in productivity growth in developed economies is just a pause in the realization of gains from innovations in process as to the economic potentials of current developed societies -- e.g. 'big data' computations, self-driving cars, the spread of 'digitization' of business and government operations.

An alternative suggestion might be that the combination of restrictions of fossil fuel use, the energy costs of such use, and the energy investment costs of creating and deploying renewable energy sources now imposes or will impose constraints on the rate of productivity gains, if any, which we can confidently project.

Exploring these hypotheses would seem to entail a merging of traditional work on productivity gains, and the use of financial techniques to stimulate realization of potentially available productivity gains, with the concepts of nonequilibrium thermodynamics, as applied to economic phenomena.

Possibly, if the concepts here suggested can be validated with careful statistical work, and other forms of field research, over time, we may better understand why ‘productivity’ in developed economies has been decreasing, what our productivity and welfare prospects may be in coming decades, and what the reach of financial and other tools available to societies may be and may not be.

If on the other hand the hypothesized thermodynamic limitations do not in fact constrain our current prospects materially, as of this time, we may get a better grasp of when they might, and proceed to offer our pick of extant policy prescriptions with greater confidence.

In either case, possibly reaching outside traditional frames of thought about finance may add to the conceptual toolkit available in this field.

Given the recent ascent into widespread scholarly discussion of non-equilibrium thermodynamics, I should to state at the outset what version of nonequilibrium thermodynamics frames the premises here used in approaching human productivity and ‘finance’.

Briefly stated, this essay proceeds from the premise that all ordered structures in the Universe are manifestations of ordered energy flows. All ‘tangible’ structures are composed of relational systems -- systems of correlated elements. Thus, the ‘order’ in the universe arises from correlations among the elements in the structures. In some, as in ‘solids’, the correlations are so stable as to stabilize both spatial dispersion, and radial degrees of freedom, over the periods of observation -- or interaction with another ordered structure, or system.

Dynamic systems at the macro scale available to humans -- systems which process energy flows and alter its internal conformation and/or relationships with external systems over time, or process -- entail both energy intake and dissipation. Ilya Prigogine condensed this seminal insight long ago. A simple and visible astronomic example is the Red Spot on Jupiter.

Thus, ‘energy’ is in a fundamental sense the sovereign coin of the realm, so to speak, in the creation and maintenance of all ordered systems.

When energy is ‘bound’, or captured, in a system, we can speak of ‘embodied energy’.

This is not mere theory. The leading explicant of the underlying dynamic nature of the Universe is Tufts/Harvard professor Eric Chaisson. In a series of exhaustively documented, elegant books and articles, he explains the energy densities, and related complexity levels, of galaxies, suns, ants, plants, humans and human societies. See for example "Cosmic Evolution", Harvard, 2001, and for beautiful illustrations .

A critical metric in Chaisson's extensive documentation of energy flows is 'free energy rate density' (the amount of energy flow through a system per unit of mass and unit of time). Life units, for example, embody higher free energy rate densities than do galaxies or suns: animals' higher free energy rate densities than plants, and humans, with their artifacts, like cities and particular elements in cities (e... Jet planes and computers) much higher free energy rate densities than animals as a whole.

In the energy scales of the Universe, human civilization is an extremely rare high free energy density phenomenon.

For a somewhat broader context, though condensed, overview for the interested general public, of how correlation mechanics relate to energy flows, on an universal scale, and in several aspects of order in the Universe, one can consult an article on 'relational order theories'.

Getting down to physics immediately relevant to civilizations and productivity within them, as humans have organized the world around them, humans have identified and constructed systems which have, to the humans, the characteristic of yielding more energy to the humans than the humans invest in them. (This is not something for nothing, however. The possibility exists because there is an external energy source for the system (e.g. the sun or wind) or energy already captured in the materials dealt with ('fossil fuel').

In agricultural societies, 'land' was often used as a conceptual catch-all for an energy yielding asset. (However, I understand the word 'capital' was derived from the Indo-European term for cattle, in a semi-nomadic phase of the indo Europeans). A fishing resource could also be so considered in some circumstances.

In recent centuries, people have come to talk more in terms of 'capital'. In generic terms, such an energy yielding system might be considered 'capital'. If it were not owned by subsets of the human society, but by the society considered as a unit, it could be considered as 'social' capital. If the rights to summon the use of a system, or resource, were allocated to a subset of the human social unit, the 'capital' could be identified with that subset.

However, over time the use of the word capitalist seems to have been associated with ownership, or decision-making rights or functions, being vested, in substantial measure, in economic units other than a 'state' -- whether families, as in the famous Italian and Jewish families, or groups of persons with various forms of corporate designation.

To the extent that 'money' -- i.e. symbols -- were used to reflect the 'value' thereof (at bottom, I suggest here, energy accessing capacity), the population subsets -- individual person or group -- allowed to 'own' -- decide the allocation of the symbols, and thus the energy flows which could be summoned -- could be, and have been, called 'capitalists'.

The current versions of 'capitalism' embody a worldwide network for trading monetary signals, involving a wide variety of 'state' and 'private' entities, which allows extremely flexible and rapid allocations of energy allocations, across political boundaries (with some limitations) worldwide. This system enmeshes, and thus constrains, entities of every personal, political, and private description.

Let us focus on a world in which systems other than 'land' (or a fishery area) were made to yield energy returns on energy invested in them.

In the fossil fuel era, such a system could be a coal mine, an oil or gas well, etc. where we have accessed energy bound in hydrocarbons by previously living systems, and learned how to liberate and turn to our use that energy. [4] In this world, more types of resource, and energy flows, are organized more flexibly, by entities including the holders of the symbols of 'capital'.

As we seek to enter a larger scale 'sustainable' or 'renewable' energy era -- that is, larger than that available from current photosynthetic processes in the biosphere -- we consider artefactual photosynthetic systems, wind energy systems, nuclear energy systems, etc.

As to all such systems specialized so as to yield to humans more energy than humans organize into them, we have come to seek to measure the 'energy return on energy invested'. In earlier systems, people counted returns on investments, either in physical units like grain, or tokens representing the physical units, or both. But the 'energy' abstraction is currently in vogue, and is, I suggest, useful in exercises such as this.

5. Initial Application of Non Equilibrium Thermodynamics Concepts to Productivity and Energy Transition Issues.

On these assumptions, we could also translate this perspective to the closely watched rate of 'productivity' gains per human actor involved. Assuming that 'productivity', as to humans, corresponds roughly to the 'energy' which the human or the system in which the human

[4] For present purposes, we can consider 'energy' to be the manifestation of altering the internal dynamics of an existing structure, or its relationships with other structures.

functions brings to ‘goods and services’ -- the fabrication, transport, communication, etc. which the human becomes involved in ‘producing’ -- productivity, as measured by the output of units specified per person work unit, would be enhanced by more energy entrainment, and decreased by less.

Generalizing this, one might posit that in a world of high EROEI, per person ‘productivity’ gains can be high, and in a world of low EROEI, they will be low.

Let us address the current slowdown in per person productivity gains observed in advanced industrial societies. We have noted that some suggest that underlying gains in efficiency -- compositional productivity, or multiple factor productivity -- are in operation but not yet manifested in ways which register in the statistical identities and measures we now use.

Let us entertain an alternate hypothesis oriented to a nonequilibrium thermodynamics framework, and a simple model which might be used to attempt to test such a hypothesis, over time, with enough data accumulation and analysis.

A candidate hypothesis would be that the energy returns on energy investments in the interconnected global economic systems are rewarding investment in energy production at lower than historic levels, and at levels which, given all the energy dissipation in cycling energy through the generation and consumption, re-generation cycles does not allow for much increase in the overall activity levels of the societies involved, over time and the continuing cycling process.

Let us unpack that somewhat dense suggestion with a simple model in which the key variables are a ‘capital’ sector (in this construct I refer to capital as physical and organizational structures), the energy return on energy which is invested into the ‘capital’ apparatus, and a population. These elements are arranged in a simple linear cycle, and the result which matters most to humans is designated as per capita wealth, in energy terms, as follows.

Per capita (energy) wealth = ((K*EROEI)-ReinvE)/P

That is, the wealth per person, calibrated in energy units (which have correspondences to ‘goods’ and ‘services’), equals the energy flow into the capital apparatus times the energy return from that apparatus per unit of energy investment, minus the energy reinvested in the capital apparatus, divided by the total population.

Stated in shorthand oriented to visually presenting the quantity relationships, the formula gives a slightly misleading picture of physical action. The physical system is a cyclical, reiterative one, as follows. The population inputs energy into the capital apparatus, the apparatus returns (and distributes) the energy back into the population, the population ‘consumes’ the energy, building some of it into population and amenities, etc., and returns energy into the capital apparatus.[5] And keep cranking.

Using a model such as this, one can imagine differing endowments in different polities -- e.g. higher or lower current capital endowments, populations, EROEI results. One can also investigate the effects of postulated increase or decrease as to each of the three factors -- population, propensity to reinvest in capital, EROEI, etc. Some interesting possible relationships are noted in the footnote.[6]

Malthus's famous views come to mind. If we were to adapt a Malthusian point of view, the K, or capital, factor was largely seen as land. The yield -- the EROEI -- of land had not shown great increases in centuries prior to Malthus, and nothing like 'geometric', or exponential, or repetitive doubling, seemed plausible at his time.

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[5] One can elaborate, or disaggregate, the reinvestment process along these lines. Imagine N capital sectors with varying EROEI at a given time period --- k1,k2,...kn. Allocate reinvestment according to its EREOI rank (this could be done by market or central allocation mechanism (within a firm or society).) Total reinvestment =SUM Reinv k1, k2, ...kn. (The notation used in this para is altered from standard mathematical notation, slightly, to ease publication typography and facilitate reading by non-technical persons.)

Now suppose that one can project gains (or losses) in EROEI at differing rates among the energy generation sectors over consecutive cycles. One could, additionally, alter the order of reinvestments by a factor, as to each, scaled to the differences in anticipated EROEI gains (or losses) as to each sector over time (cycles).

In effect, we now do this, roughly, by giving tax credits for investments in selected sectors, and letting the investment markets then respond to the resulting weighted returns. This device is designed to accelerate the path to economies, or EROEI gains. It assumes past rates of gains, as in photovoltaics and wind energy, can confidently be expected to continue and produce large efficiency gains over future time periods. The Bloomberg report cited herein makes this assumption as to photovoltaics and wind energy, over coming decades, and there is a good deal of experience and current activity to support this assumption.

(Note that the bias, or acceleration, given the cost-decreasing sector withdraws energy from other sectors otherwise allocated to them strictly on the current cycle EROEI rankings. Acceleration has its costs, as always, and they are complained of discussions of energy public policy.)

[6] One could do combinations of variables of varying magnitudes -- e.g. large population, low capital, high or low EROEI; small population, a standard or average per capita capital factor, and an high EROEI; populations with differing allocations of energy flow back to capital (in some current parlance, 'savings'), and so forth.

As to the United States, for example, one could note that the high capital per person ratio offered promise for maintaining relative international productivity standards should there be a high reinvestment rate. Also, one could model a high savings economy, like China, by inserting a relatively high reinvestment rate in the equation. (Of course, one might also try to build into the model the presence or absence of efficient reinvestment allocations as among candidate capital use sectors -- China currently is charged with having excessive allocations to nonproductive capital additions.)

So if one assumed that the total population would increase faster than did energy production from land, using historic forms of agricultural technology, the result would be obvious and rather grim, especially for those in the human population closest to the edge of survival. People would live more poorly, or some of them would, or some would have to go -- to be subtracted from the equation. So this model would predict, and so Malthus seems to have proposed, with perhaps less sympathy than one might like.

Let us now put in this formula the Industrial (or fossil fuel) Revolution. Suddenly (in historical terms) EROEI skyrockets -- let us say up to 50 times the energy input. The population can expand (improving food supply in various energy-fed ways), the energy using apparati generally (goods and services) can expand, and the capital factor can increase. The cycle becomes wonderfully virtuous, and humanity bestrides the Earth beyond its agricultural dreams.

But now let us suppose there are limits to the extent the capital factor can increase, or the EROEI begins to decrease, or both. Depending on how one varies the critical factors of population size, capital stock, and EROEI, many scenarios can be produced, as noted before.

To focus on one scenario. Let us suppose an equilibrium situation -- as economists are wont to do. Let us suppose that all three factors are locked into a steady state cycle -- the population is fixed, the EROEI is fixed, and the capital stock is fixed. There is no 'growth' in the system as a whole. There is no productivity growth, there is no capital stock expansion, and humans might count themselves fortunate simply to participate in an eternal cycle. (Sounds rather vedic, doesn't it? Perhaps the world might have so appeared to the everyday Brahmin at some stages of the Indian civilization.)

Money just cycles in constant units, at constant totals, also -- though just how that would look will require some more imagination.

Let us now look ahead in the current era. Could we get locked into such a cycle? Such a result might occur as a result of declining EROEI, in the aggregate, and populations reconciling themselves to their circumstances (if they did not get so disappointed and frustrated as to blow up the whole apparatus, with even worse results.)

Many doomsayers sensationally have projected such futures, and worse. And many socially responsible persons, who are not addicted to sensationalism but view the future with concern, earnestly counsel that we reconcile ourselves to having less energy wealth, and living less, in their view, profligately.

But let us sketch a more optimistic scenario for a few centuries ahead.

Let us continue to assume that the EROEI on fossil fuels decreases, and/or fossil fuel capacity is capped in order to avoid overheating the whole human complex, with major losses of system function and human welfare.

But our specialists advise us that life on earth taps only a very small fraction of the solar energy impinging on earth, we also tap a small fraction of the wind energy available, and if we are clever, farsighted, and disciplined enough we might replace the fossil fuels, at levels comparable to or above current civilization energy levels, at EROEI ratios sufficient to maintain our population levels and our per capita welfare, and also feed back into the capacity machinery enough energy to keep that machinery, and the whole system, stable and growing.

May I suggest that the reader please note in that paragraph each and all of the conditions apparent and implied which would have to be fulfilled to make this hopeful scenario a global reality?

Put in these terms, this continuation of the recent extremely virtuous cycles we have been experiencing seems a bit daunting, if not unlikely. There are just a lot of very large and complex processes to get right, real time, on the fly, with no global do-over readily visible if we somehow crash the global system back to much lower levels of productivity and population.

But, I submit, if humanity is not to go on a severe diet at some point, this is clearly the situation which will have to be managed. We humans have a very big and tricky energy supply transition coming up.

However unwelcome, the problem is clear.

Also unwelcome, there are many uncertainties involved in dealing with it.

First, we may not know just how rapidly the energy supply transition can occur.

Vaclav Smil counsels that we think in terms of a century or so. Smil has a great deal of historical evidence to support his view. Vaclav Smil (2011), *Global Energy: The Latest Infatuations*, American Scientist.

Others suggest that with more sophisticated management of energy supply and consumption arrangements (drawing to a significant degree on ICT technologies), and other means of continuing to improve on energy/gdp ratios, the coming transition could be managed more rapidly. The current Administration in the United States is pursuing an aggressive program to facilitate adaptation of the electricity system to increased proportions of wind and solar electricity generation. Europe also has an extensive effort to do so. The Presidents of Canada, the

United States, and Mexico recently announced a plan to obtain 50% of the energy for these three countries from ‘clean’ sources by 2025.

As of this writing, a 2016 projection of the Bloomberg New Energy Finance group -- evidencing an optimistic bent, but still a generally competent group -- projects that by 2027 renewable electrical energy sources will cost less than operation of fossil fuel plants. BNEF projects that by 2040 renewable technologies will improve their cost levels 40-60% and fossil fuel production will have shrunk to less than 50% of total electrical energy production worldwide. In the advanced economies of Europe and America, the fossil fuel shares will have shrunk to a third or less of total electrical energy supplies. The major carbon emitting sources of energy supply will then, Bloomberg suggests, be India and other South Asia nations.

In addition, this group projects that about 35% of new light vehicle (cars) sales will be electric vehicles. This in effect projects substantial momentum toward reducing the demand for liquid hydrocarbon fuels.

Also, we do have a history of squeezing more GDP out of a given amount of energy, over recent decades.

Second, we may not know with sufficient clarity what system wide EROEI levels are required to maintain the high levels of free energy densities which we now enjoyed in highly industrialized civilization. As of this point, this author has not seen a thorough treatment of this issue, with the quantity of data and intellectual rigor one would desire. A currently circulating guess is @10/1. See also. But we are guessing and approximating.

Many have argued that humans could enjoy high levels of welfare at significantly lower energy flow levels than now prevails in the most developed countries, like the United States. Hopefully this might prove to be true.

Importantly, as to uncertainties, we may not now know how well the public in the industrialized areas can come to understand the requirements of the transition, and whether these publics will have enough patience and foresight to soldier through the required transitions.

Assuming all these uncertainties, we still must attempt to project a path forward.

Let us therefore trace out another possible scenario, designed to stimulate current inquiry, and to illustrate the value of using an energy flow base for thinking about economic and social phenomena, in addition to the traditional modes of analysis of aggregate economic behavior.[7]

[7] In advancing the non-equilibrium thermodynamics paradigm, I am not suggesting a lack of continuing practical value in traditional methods of economic analysis. As a sort of parallel, we still use Newtonian

This scenario is chosen to reflect the possibility that we are at or near a difficult point in our energy base transition, but we can plot a way forward.

This scenario combines optimism and pessimism. It might be called a ‘valley of disappointment’ scenario. That is the pessimistic part. The optimism is reflected in the projection that only a valley, not a cliff, looms before us.

I here assume that fossil fuel supply will demonstrate declining EROEI over nearby time periods, and for decades to come.

On the other hand, there have been and currently are significant gains in the EROEIs of renewables. But it is obvious that even if and as this gain continues, there has to be a major, and continuing, process of reorganizing our energy/economic systems to handle things the ‘renewables’ do not currently handle as well -- e.g. nighttime, severe cold, climate fluctuations over annual cycles, ease in transport use, storability ... just to name a few. This reorganization itself has energy costs.

So let us project that we are now in, or entering, a situation in which the fossil fuel energy recovery rates are declining, and the renewable energy yields are increasing, but are currently only a bit above the base rate needed for advanced civilization[8], account only a small part of energy supply at this moment and need extensive energy-consuming complements to fill out the entire range of energy uses.

If we make these key assumptions, or projections, we might predict a high likelihood that our societies could encounter the following situation as they go through the fossil-to-renewable transition, however long that full transition takes.

- A slowdown in global, composite EROEI levels relative to historic fossil fuel boom era EROEI levels,
    - and thus widespread, aggregate slowdowns in GDP, or GDP growth
    - and related slowdowns in per person productivity gains,
    - and thus slowdowns in consequent ‘standard of living’ gains.

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physics, in a number of very useful ways, after digging down to the quantum mechanics and relativity constructs.

[8] This succinct summary by Ramez Naam suggests that solar EROEI are a tad above the hypothesized 10/1 ratio, and rising. http://rameznaam.com/2015/06/04/whats-the-eroi-of-solar/ A group led by A.S. Hall mentions a similar order of magnitude figure.

- Even if the renewable energy sources were eventually to produce high and reliably increasing levels of energy flows in human societies, efficiently spread throughout our societies, we could see
    - lags between investment in the renewable energy sources, and the related complexes which are required to make them broadly and efficiently usable, and their full effectiveness in gaining and sustaining energy flow patterns higher than current energy flow patterns, and thus
    - human societies enduring some decades of transition as the processes of developing the energy sources and integrating the energy throughout the economic and social system were worked through.

- All this leading to
    - A lull in standard of living gains, if not a period of decline, and
    - slow progress in improving them again. And, consequently,

- as these slowdowns occur, and a resumption of something like historic welfare gains seems remote, considerable dissatisfaction arising in populations which are accustomed to rapid gains in 'welfare', or standard of living. This dissatisfaction could be manifest in several ways, including conflicts in programs and priorities as between differing strata of societies experiencing differing levels of success and comfort.

Does what we now are seeing in the 'highly developed', extremely entitled populations of America and Europe resemble an early stage in this projection?

Of course, even if this perspective were to track the underlying situation accurately, there would be national and regional variations in how human societies could work their ways through the postulated transitions. For example, the large populations of China and India still can 'grow' in energy flow and welfare for a while. But if this reading of the energy landscape were to be accurate, they would encounter transition limitations as they go along. (Indeed, BNEF and others are now in effect spotlighting India as presenting a major issue which needs urgent address, if we are to avoid excess heating of the atmosphere and international peace and coherence in a renewable energy transition.)

This picture is rather sobering. However, The 2016 Bloomberg new energy investment scenario seems to suggest that much of the transition in electricity supply in more-industrialized countries could be well under way by 2040 -- a matter of only a little over two decades. By this time, wind and solar costs in dollar, or currency terms -- presumably reflecting declining energy costs per productive unit and therefore higher EROEI returns -- would have dropped 40-60%. Such a rate of progress could make less onerous the 'valley of disappointment' scenario sketched above.

BNEF seems to suggest that light is already visible at the latter stages of the tunnel, so to speak -- if we understand our situation and can keep on track through the tunnel.

This analysis focusing on electricity generation does not reflect liquid fuels trends, affecting transportation. These trends also will have significant, world and economy wide, effects. But I will suggest -- hopefully -- that a combination of electrification of transport, adaptations of various sorts to higher transport costs, and solar electricity cheap enough to make competitive chemical fuels may fit into a larger 'valley of disappointment' scenario having sufficient transport capacity at the latter stages of the tunnel to service high energy human civilization.

6. Implications for Financial Policy

In this sort of scenario -- and in numerous others which could be constructed by elaborating the cyclical model suggested -- would the roles of 'finance' differ from those which are now prescribed (on the heretofore prevailing assumption that energy flows through all relevant economies will suffice to support further 'growth', en masse and for individuals, without the thermodynamic restrictions suggested above) ?

At least until economic investigations reveal whether constraints on production of 'goods and services' rest on underlying EROEI factors rather than unassociated cyclic factors or unfortunate social organization practices, 'policy makers' may be unclear whether they may just assume that 'fiscal' stimuli will draw on an underused and available well of production and productivity-increasing opportunities on which to spend money tokens, or whether their justification rests solely on a judgment that they, better than the market, can discriminate between higher EROEI possibilities and less productive ones. Otherwise, if the economic system were operating at its then-current thermodynamic potential, 'crowding out' of other activities might merely subtract from gross welfare.

However, this author would not exclude the possibility that persons with a good overview of the economic system could, in a slack period (as well as a 'normal' period), choose to funnel resources to long term thermodynamic gain as well as or better than an unguided or unassisted market. For example, a comprehensive national electricity transmission system might substantially facilitate more rapid development of efficient renewable energy systems, and if this is so pursuing that objective in a downshift period would be hard to criticize successfully. (This is not to say it would not be criticized.) In the United States, we have a long history of 'public works' programs (e.g. canals and railroad encouragement) which accord well with the operational concept of channeling dynamic energy flows.

As to monetary tools, on the face of it, a regime in which low interest rates prevailed would seem to accord with a relative scarcity -- whether temporary or long term -- of thermodynamically fruitful (in customary language highly productive) investment opportunities. That is, low interest rates would reflect generally low returns to investments.[9]

In contrast, if one expected that 'natural forces' -- e.g. 'innovations' -- would soon replenish the inventory of potentially rewarding opportunities, one might just hold steady and wait. One might assume that the 'wait' might be for only a few years.

If on the other hand one were guided by the 'valley of disappointment' construct, premised on basic EROEI arguments, the 'wait', and the period of low returns on 'capital' generally, might go on for some decades. And a great deal of adjustments in matters such as annuities, pensions, bond integrity -- indeed, public and private finance generally -- would be compelled.

This 'low returns' era might be accompanied by aggressive allocation of capital to higher-EROEI related investments, by a variety of finance related means. And care would need to be taken to avoid or minimize 'bubble' phenomena, in which finance tokens clumped on momentarily attractive but non productive holdings or activities.

Thus, there would seem to be a strong case for monetary policy functionaries and advisors to focus clearly on creating, examining, and refining non equilibrium thermodynamics, EROEI oriented, analyses of economic phenomena. Doing so would probably take several years of research, review, critique, and testing of data and hypotheses. But the yield, so to speak, could be of great value to the economic system as a whole.

If this work is done, and our current productivity levels persist, the 'valley of disappointment' hypothesis may be confirmed in whole or substantial part, and we may learn enough to get a better picture of the path of the transition before us.

7. Globalization

There is no assurance given to humankind that the sort of high energy, daily continent hopping, globally managed system which we have begun to develop will continue indefinitely.

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[9] The basic logic is as follows. If economic agent A wants to attract capital -- energy -- to activity A1, he/she/it (A) must offer a set of returns over time equivalent to what a pool of money token holders would expect to gain over time from the energy resources which they could summon were that energy allocated to alternative deployments. If the alternatives pool had few high return options, the capital seeking economic agent would bid accordingly -- that is, up to the level which would attract enough 'capital' -- energy -- to put into effect A's desired program at a level and expected return deemed sufficient for A.

It is true that global coordination of dynamic 'nations' of humans is an inherent potential of the hierarchical order building system of the universe, touched upon in the section on nonequilibrium thermodynamics.

But the universe is built on a stochastic, or random, substratum. High energy life 'civilization' is an extraordinarily rare phenomenon in our universe. It has taken billions of years to evolve here. Life structures have repeatedly collapsed in the history of the Earth. And we fractious, cognitively limited, diverse babbling apes may not have what it takes to pull this off on a sustained basis.

If we do not make the sustainable and sustained energy transition we now imagine, the odds of maintaining current levels of global interactions would seem nil. If the process of transitioning to sustainable energy flows encounters a pinch, or breakdown, in the energy throughput of human societies, then international trade and international institutions seem surely likely to constrict, if not to wither.

Before we had nuclear powered aircraft carriers we circumnavigated the Earth in wind powered ships, and we had a 'silk road' through Eurasia.[10] But cheek by jowl, elbow jostling, machine language translation, massively internet informed, hundreds of thousands of persons flying internationally on a daily basis we did not have, and might not have again.

Between agricultural era interactions and a thoroughly integrated, high energy human ecumene lie a vast range of conceivable degrees and types of global integration. We must do the best we can in this territory. What does this analysis suggest be done about the slowdown in productivity and current widespread signs of dissatisfaction with the combination of 'capitalism', (more or less) free trade, and European and global institutions?

First, both the 'elites' and the 'workers' in various polities need to understand as clearly as possible both any limits on productivity, or more generally returns to labor, encountered, and the advantages, as well as discomforts, of the combination of global integration and what we call 'capitalism'.

As to returns to labor, I have suggested the possibility of a thermodynamic factor. Others suggest a pause in visible productivity gains while underlying efficiencies work themselves out. Some have suggested that the 'catch up' in productivity in less developed countries has put competitive limits on rewards for those physically producing (as distinguished from financing and managing)

[10] I must note that elements of 'globalization' have been going on for several centuries. The history of 'colonization' is a part of that larger picture. But the attempt at fully global coordinating mechanisms such as the United Nations, the World Bank, etc., is the work of the last two centuries.

tradeable goods and internationally substitutable services. There may be other factors involved. Interactions between such factors may be involved.

If the 'elites' and the 'middle' and lower 'classes' do not understand why they are not benefited as hoped or expected, they may opt for strategies which worsen their situations, rather than better them, over time. Those 'whites' who want to opt out of a world in which most humans have more melanin in their skins, and workers in wealthy societies who wish to avoid entirely the effect of other workers around the world becoming more productive, will need to realize that another planet free of these imperfections is not available to them.

Even so, as to returns to, or welfare of, 'workers', the internal organization of States needs to reflect shares of welfare which maintains both political integration within the State, and State participation in a productive international system.

In an assemblage of groups, what matters most are the relationships between the groups, not the internal arrangements within the groups. But the internal groups must have enough cohesion to support the relationships between the groups. In human terms, if the 'nation' doesn't work, then there is nothing to internationalize with. If the 'nation' cannot cohere, given the effects within it of its interactions with other groups or entities outside it, the compact between groups will not persist -- sustain continuous cohesion.

In getting human groups to cohere productively, one must muster enough advantages to overcome the inherent tendency of the constituent groups to maintain the identities which they had previously formed.[11]

If we return to the non-equilibrium thermodynamic explanation of the construction of ordered structures, we can find deeper explanations than heretofore used both for global 'trade and commerce' and for 'capitalistic' institutions.

First, thermodynamic order building is an inherently combinatorial process. Systems draw upon diverse elements, or subsystems, in forming unique and effective, or sustainable, constructs. This Earth has a vast treasure trove of resources and potential combinations thereof. This is the foundational basis for the gains of 'trade.' Secondly, the 'capitalistic' process uses both State

[11] In humans, the making of a successful group --- let us say a tribe -- involves some distinction between this group and others -- else why do we stick together at all? But then getting the tribes to work together necessarily involves surmounting the tendencies of each set of group members to stick to themselves rather than interact, individually or group-wise, with others. Let's face it, caution concerning, if not fear of, the stranger precedes integration. Integration happens when it pays the groups to work together. So 'globalization' involves getting a whole lot of -- a global set of -- groups to suppress their mutual aversions and hostilities, and find mutual advantage together. Notwithstanding that the participating groups have significant differences in the modes of organization within them.

and nonstate actors[12] to route resources (energy sources and flows) to productive uses, through 'financial' markets, with remarkable speed, discrimination, and transactional economy.

Best we recognize and accord with such fundamentals. In the long run, human systems will accord with these realities, or suffer greatly from not doing so.

This author cannot predict each and all the forms of multinational combination which best conduce to maintaining high energy civilization on a global scale.[13] Nor can he attempt to guide in any great detail all the possible ways in which 'States' might organize themselves internally to find, or feel out, how sufficiently to enfranchise socially and economically their inhabitants so as to be both productive within their boundaries and sufficiently content to maintain international cooperation.[14] Even to offer some guidelines would prolong this already lengthy article. But he can suggest that priority must be given to achieving the necessary large-scale transition between fossil and sustainable energy sources, both within and between states, or our entire civilizational construct will deconstruct, and therefore all parochialisms -- all past preferences and practices -- must yield to this demand. Only in getting through the valley of disappointment can our common hopes be realized, and our frustrations assuaged.

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[12] The long-running conflicts and contrasts between 'socialist' and 'capitalist' forms of organization reflect to a substantial degree different preferences between political mediation of resource flows -- by political, or 'state' mediation of substantially all resource allocations -- or by 'market' allocations allowing substantial decision-making for non-state actors, in addition to State actors. In virtually all current 'developed' and 'developing' national systems, there is some mixture of both 'state' and 'non-state' resource-allocation decision-making entities. But even in systems with more-substantial 'state' roles, global financial markets impose constraints and influence energy allocations. And since thermodynamic energy returns on energy investments determine the success or failure of human social systems; this would appear to be a good -- and necessary -- thing.

[13] In 'nature', not all type of units, let us say cells, for example, have achieved multiple unit cohesion in, let us say, for example, multicellularity, in the same ways. The history of multicellular creatures on Earth is a history of a great deal of experimentation, or 'trial and error'. Viable multicellularity has been realized in a variety of ways (e.g. plants, animals and fungi). Thus, one might project that coherent, group subsuming 'globalism' is an experimental process. We are feeling our way.

[14] Such things to consider might include efficient and widespread health and education systems, energy savings programs, minimum wages, worker retraining systems, longer working lives, better access to workplaces for females in some Muslim lands, and much more.