**In Press, Science & Society**

# The Limits to Entropy: the Continuing Misuse of Thermodynamics in Environmental and Marxist theory

**By David Schwartzman**

**Abstract**
The continuing use of Georgescu-Roegen's theory of entropy by neo-Malthusians as foundational support for their views comes as no surprise. Lately, those warning of a Hubbert Peak apocalypse have commonly drawn from the same conceptual well. But unfortunately even Marxist scholars still do the same. Paul Burkett's recent paper supporting Georgescu-Roegen's fourth law of thermodynamics attempts to seek convergence of Marxist theory with ecological economics. However, this attempt is undermined by the very shaky foundations of Georgescu-Roegen's theory. In particular, Georgescu-Roegen's proposed fourth law conflating isolated and closed systems is in contradiction with thermodynamic theory and leads to false conclusions regarding recycling and the prospects of a solarized economy. Red-green theory and practice should be firmly based on robust thermodynamic theory. With this guide and subject to the contingencies of political struggle, an ecosocialist transition in this century is within reach.

Can an effective strategy to achieve a society sustainable for both humans and nature rest on a fallacious theory of how energy and matter interact? The answer should be obvious, but unfortunately this is not a rhetorical question because such a theory now has wide currency among environmental and even Marxist writers. This discussion will provide a critique of this theory and suggestions for a more defensible approach. I submit that only a red green practice informed by the most robust theories and knowledge derived from the natural and physical sciences and an historical materialist approach to social change can measure up to the immense challenges now facing humanity.

There is now strong evidence that catastrophic effects of global climate change will occur unless radical steps are taken in the coming few decades to effect a solar-based energy transition from the present reliance on fossil fuels (e.g., Leggett, 2006; Milliken, 2006; Harvey, 2006). Further, defeating the main obstacle to this transition, the US imperial project, is likely necessary to its achievement. This struggle on a transnational scale will open up new possibilities for 21st-century Ecosocialism, adding the ecological dimension to Hugo Chavez's inspiring vision, green to red.

Such is the urgency of constructing a robust red green theory and practice. However, an influential Marxist contributor to this project has recently reasserted the relevancy of a widely discredited new “law” of thermodynamics. I will argue that this same misinterpretation of thermodynamic theory has already fertilized a wide range of regressive ideologies that are serious obstacles to achieving a sustainable future. Further, the continued appropriation of fallacious thermodynamic interpretations undermines the grounding of effective red green theory and practice. The same attempt to introduce these interpretations into Marxist theory of the material aspects of production and consumption and societal interactions with nature brings neither clarity nor illumination.

The fallacious “law” of thermodynamics in question is Georgescu-Roegen’s fourth law. While this law once had superficial credibility because of the undeniable contributions of its inventor, it is no more valid than the repudiation of modern physics by those who claim the invention of perpetual motion machines.

I previously critiqued the misuse of thermodynamic concepts, especially entropy, in environmental green and Marxist discourse, in an attempt to reground the project for Marxian communism on robust physical theory that comes to terms with ecological issues (Schwartzman, 1996). In particular, this misuse has been largely drawn from the influence of Georgescu-Roegen’s work. While Georgescu-Roegen surely deserves credit for founding the field of ecological economics by virtue of his influential writings, especially The Entropy Law and the Economic Process, and for stimulating discussion regarding waste and the economic process, his thermodynamic theorization has received critical rebuttal from both within and without the discourse of ecological economic (footnote 1). While some scholars still defend Georgescu-Roegen’s thermodynamics (e.g., Mayumi and Giampietro, 2004), the predominant view now seems to acknowledge the fallacy of his fourth law, because of its conflation of isolated and closed systems.

Nevertheless, Georgescu-Roegen should be credited at least with a useful error, if the thermodynamic fallacy of his fourth Law is understood. “Despite the flaws in Georgescu-Roegen’s definition of a Fourth Law, … His focus on the dispersal of materials and limits on recycling foreshadowed the development of industrial metabolism and industrial ecology …in which the analysis of material cycles is used to understand how production and consumption impact the environment, and how to design new technologies that reduce such impacts” (Cleveland and Ruth, 1997).

In spite of its refutation from a wide range of scholars, Georgescu-Roegen’s thermodynamics is still very influential, especially among neo-Malthusians and lately

Hubbert Peak enthusiasts. This continued attraction of Georgescu-Roegen's views is not surprising, but what is disturbing is the more than occasional appropriation of his fallacious thermodynamical theories to the red green project of ending the global rule of capital reproduction while establishing an ecological bond of society with nature.

So this paper will revisit this continued invocation of Georgescu-Roegen's theories in the hopes of strengthening red green theory and practice. After a brief review of the laws of thermodynamics and the use of Georgescu-Roegen's theories by Neo-Malthusians and other non-Marxists, I will concentrate on a recent paper by Paul Burkett (2005), a well- known Marxist scholar with many valuable publications on red green theory (e.g., Burkett, 2003; Foster and Burkett, 2004). (Burkett's 2005 paper is included with minor revisions as chapter five in Burkett 2006). I conclude with a reexamination of the real potential of achieving the necessary material conditions for ecosocialist transition from global capitalism to solar communism.

**The Three Laws of Thermodynamics, is there a Fourth?**

I will begin with a short summary of standard thermodynamics and its three laws (see Atkins, 1984 for a clear discussion). Actually there are already four laws counting the "zeroth law", which grounds the concept of temperature. The first law asserts the conservation of energy (after Einstein, mass and energy). The second, the important one for our purpose, captures the fundamental dissymmetry of the universe, in which the distribution of energy changes in an irreversible manner. This irreversibility is measured by the production of entropy. There are several different ways of expressing the second law. One is that work can be totally converted into heat but the reverse is impossible. Entropy is defined as the heat supplied to a system divided by its absolute temperature (e.g., 0 deg Celsius, the freezing point of water, equals 273 deg Kelvin on the absolute temperature scale). Temperature is a measure of the intensity of thermal vibrations in any material system, its kinetic energy, i.e., active as opposed to potential energy, Zero degrees on the Kelvin scale is the lowest temperature conceivable, at which, in theory, all thermal vibrations cease, but this state is physically unattainable (see third law). One other formulation is relevant here: heat cannot flow from a cooler to a hotter reservoir without any other change (i.e., work must be done). The increase of entropy is equivalent to the increased inability of an *isolated* system to do work, resulting from the degradation of low entropy energy into waste heat (an *isolated* system is defined as being closed to both energy and matter transfers in or out, while a *closed* system is only closed to matter transfers).

The third law applies to matter at very low temperatures, forbidding it to reach absolute zero in a finite number of steps.

So is there a fourth law recognized by modern physics? Could modern physics be wrong and guilty of suppressing an unconventional yet valid new law for over 30 years (Georgescu-Roegen, 1970)? To answer this question we will first look at the specifics of Georgescu-Roegen's so-called fourth law, since it is foundational for such a diverse discourse as well as being at the core of Burkett's argument. A concise expression of his so-called fourth law is found in Georgescu-Roegen (1980, 304), where two formulations are given: First,
"unavailable matter cannot be recycled; second "a closed system (i.e., a system that cannot exchange matter with the environment) cannot perform work indefinitely at a constant rate. " Burkett quotes another very similar formulation (Georgescu-Roegen 1981, 59-60) which in addition to the second statement above posits that "in a closed system available matter continuously and irrevocably dissipates, thus becoming unavailable' and
that ''complete recycling is impossible'. Here his definition of a closed system follows its standard definition in thermodynamics as already pointed out. If we substitute "isolated" for "closed" (an isolated system means there are <u>neither</u> matter <u>nor</u> energy transfers between the system and its environment) then Georgescu-Roegen's second formulation (an isolated system cannot perform work indefinitely) is equivalent to the second law of thermodynamics. As I previously argued, for an economy run on fossil fuel energy, which of course has finite reserves, the second law simply indicates that energy to do work is not renewable, i.e., you cannot reuse waste heat ad infinitum (true of waste heat from using solar energy as well) nor can you regenerate the low entropy energy reserve (with solar energy the sun does this for you!). Before engaging in further discussion of this alleged fourth law, we will first see how those outside the red green discourse have recently used Georgescu-Roegen's thermodynamic theories. This will illustrate the importance of clarity and accuracy with respect to the thermodynamic grounding of red green theory. How can red greens effectively critique regressive and harmful ideologies while adopting their same fallacious theoretical sources?

**Neo-Malthusians, Limits to Growth, the Hubbert Peak and Georgescu-Roegen**

If the <u>dominant</u> political economy of global capitalism is assumed to be largely irrelevant to explaining humanity's and nature's sorry condition, then pointing to the present size of human population and its forecasted growth as the primary cause will be user-friendly to the continued rule of capital. Biology triumphs over political economy. Thus, we find prominent environmentalists and ecologists claiming that the Earth's carrying capacity is now exceeded by the global human population size (e.g., Rapley, 2006; Pimentel and Pimentel, 2006, Pimentel, 2006). Garrett Hardin (1993), one of the most influential neo-Malthusians of the 20th Century, argued that the 2nd law of thermodynamics is the physical basis for the limits to a sustainable human population level. As Gillot and Kumar (1997) pointed out, Hardin assumed the Earth is a isolated system (p. 163) with Hardin (just like Georgescu-Roegen) ignoring the real potential of tapping the huge solar energy flux to the Earth's surface by high efficiency technology for humankind's use.

James Lovelock of Gaia fame has reiterated his long-standing neo-Malthusian views in his new book (Lovelock, 2006). Here we find the following assertion:

The root of our problems with the environment comes from a lack of constraint on the growth of population...the number...has grown to over six billion, which is wholly unsustainable in the present state of Gaia, even if we had the will and the ability to cut back. (140)

Lovelock elaborates on this theme in a recent interview (Revkin, 2006):

Q. You say in the book that sustainable development is a fantasy, essentially, and you have a different notion for what needs to happen, of "sustainable retreat."

A. At six-going-on-eight-billion people, the idea of any further development is almost obscene. We've got to learn how to retreat from the world that we're in. Planning a good retreat is always a good measure of generalship.

Some ecologists have gone so far as to advocate the elimination of 90% of the world's population by airborne Ebola (see report by Mims, 2006)—with protective measures presumably being provided for the privileged 10%, living in gated communities? This genocidal prescription recalls Rifkin's (1989) more modest claim that a pre-industrial global population of less than 1 billion people is required for a sustainable planet, though he never apparently advocated genocide to reach this goal.

Many neo-Malthusians still ground their arguments with Georgescu-Roegen's version of thermodynamics (e.g., Campaign for Political Ecology, which includes well known advisors such as Jonathan Porritt and Norman Myers). From the CPE website:

"Our guiding concepts are limits, diversity and stability. The key issues are overpopulation, overconsumption and uncontrolled technology." "renewable energy may, and indeed must, play an increasingly important role in future but it will be difficult or impossible for it to match demand unless total energy consumption is also greatly reduced." " The thermodynamic and ecological limits to growth are explored in:

Ophuls, W, 1992. Ecology and the Politics of Scarcity (Freeman)
Rifkin, J, 1989. Entropy (New York: Bantam) A popularization of the work of the economist, Nicholas Georgescu-Roegen, whose writings are well worth detailed study.”

Other examples of this argument are found in the work of John Attarian, (2005) and that of Jay Hanson (2001); the latter acknowledges his debt to Georgescu-Roegen: “ No so-called "renewable" energy system has the potential to generate more than a tiny fraction of the power now being generated by fossil fuels! " Others drawing from Georgescu-Roegen include Huesemann 2001, 2003, and numerous believers in a Hubbert Peak apocalypse, a prospect to be discussed shortly. The assertion that total energy consumption must be greatly reduced, along with population size, follows directly from Georgescu-Roegen’s “fourth law” and his deep pessimism that solar energy would ever replace depletable energy sources (see Schwartzman, 1996).

A systematic refutation of these neo-Malthusian views is not the subject of this paper, so the reader should go elsewhere (e.g., Cohen, 1995; Boucher, 1999). My brief rebuttal to Rapley (2006): the Earth is too crowded—but with billionaires. Population stabilizes with reduction of poverty and empowerment of women. Yes, radical changes must be made to realize global sustainability: solarization, demilitarization, agroecology. The challenge is political and economic, not one of reducing population size. Another world is possible if the global "excess" population is sufficiently organized to force it into being, constraining the rule of capital that enriches the few, while bringing immiseration to the many.

The widely cited writings of Herman Daly supporting a steady-state economy were profoundly influenced by Georgescu-Roegen (see critique in Schwartzman, 1996; Boucher et al., 1993). Georgescu-Roegen’s and Daly’s concepts have been foundational for advocates of “limits to growth” and a steady-state (in this context, zero-growth) economy (Czech, 2000; Czech and Daly, 2004; Attarian, 2005).

Lately, the spectre of Hubbert Peak, the likely peak in production of oil in the next 50 years if not sooner, has been added to the mix of neo-Malthusian and anti-growth ideologies (see e.g., Hanson, 2001). There is little doubt this peak will come sooner or later in the 21st century (Smil, 2003; WorldWatch, 2006), hopefully sooner, corresponding to the rapid shift to a global renewable energy infrastructure forced by transnational red green struggles. Given the now undeniable link of fossil fuel consumption to global warming and other multi-fold negative impacts to humans and nature, it will be catastrophic to wait for a production peak driven by the actual recoverable geologic reserves of oil, or a shift back to coal (see Leggett, 2006).

**Georgescu-Roegen's "Fourth Law" and Its Recent Support by Marxist Scholars**

Two prominent and influential Marxist scholars have recently drawn from Georgescu-Roegen's theory of entropy. Joel Kovel's appropriation of Georgescu-Roegen's theory was critiqued in Boucher et al. (Kovel, 2003; Boucher et al., 2003). A more recent paper by Paul Burkett (2005) supports Georgescu-Roegen's theory of entropy in an apparent attempt to seek convergence of Marxist theory with ecological economics. The very shaky foundations of Georgescu-Roegen's thermodynamic theory, however, undermine this attempt. Nevertheless, I thank Paul Burkett for reigniting a discussion on the relationship between Marxist theory and ecological economics. Red-green theory will surely be enriched by engaging in a dialogue with scholars dedicated to developing ecological economics, who have critiqued neo-classical economics for its neglect of ecological concerns (see Costanza et al,1997, for an overview, Martinez-Alier, 1987, for an interpretation open to Marxist concerns).

As discussed earlier, a common if not predominant use of Georgescu-Roegen's theory of entropy since Rifkin's popularization in the 1980s has been to create the illusionary appearance of a robust physical basis for neo-Malthusian and anti-development ideologies, not to support a Marxist critique of neo-classical economics. Hence Burkett's embrace of Georgescu-Roegen's theory is curious given Burkett's own valuable critique of neo-Malthusian views (Burkett, 1998).

In Rifkin's work, the entropy concept is extended to its apocryphal limits. Entropy appears as a pollutant, as an indicator of cosmic disorder, the inexorable outcome of all economic activity, the mother of ecocatastrophe. (Georgescu-Roegen enthusiastically endorses Rifkin's treatment of the subject (Georgescu-Roegen, 1980). Rifkin, as noted, favors a pre-industrial global population of less than one billion people, and rejects the use of computers since they generate entropy (1989 edition, 190-191)! Should we wonder whether Rifkin's more recent books were composed on a word processor rather than a less entropic typewriter?

Entropy is too abstract and coarse a concept to illuminate most issues in the environmental discourse unless the full context of its use is thought through—the "ascent from the abstract to the concrete" in Marxist epistemology (Ilyenkov, 1982). Its invocation in the environmental discourse commonly serves little purpose other than to avoid clarity while creating the illusion of rigor because a concept from theoretical physics is used. Is entropy a useful measure of unsustainability? A consideration of the physical entropic flux (roughly equivalent to the radiant energy flux) from the Earth's surface should demonstrate that appealing to anthropogenic (man-made) entropy production as a measure of negative environmental impacts fails to recognize their real qualitative aspects.

This entropic flux is dominated by the natural heat production from both solar radiation interacting with the Earth's surface and incoming radiation from the greenhouse effect. Any plausible anthropogenic contribution is trivial. The greatest potential anthropogenic contribution arises from global warming. Since to a good first approximation the entropic flux is equal to the incoming solar flux divided by the absolute temperature (Schwartzman, 1999, 2002, 162-163), a 5 deg C global rise in surface temperature will l*ower* this flux by about 2%, which is derived from the ratio of absolute temperatures (288/293), the global incoming solar energy flux being the same (recall that the denominator of the entropy flux expression is always the absolute temperature). Whatever the change in entropic flux arising from changes in the Earth's surface temperature, the entropic flux in itself will tell us nothing about actual impacts of global warming, which are both the linear and nonlinear outcomes of fossil fuel consumption and other sources of anthropogenic greenhouse gases. The concrete linkage of cause and effect must be worked out from application of the sciences of biogeochemistry, climatology, oceanography, ecology etc. Likewise, while the entropy of mixing gives some insight into general aspects of pollution it fails to capture the relevant qualitative aspects so critical to the health of humans and nature (Schwartzman, 1996).

On a cosmological scale, the increase in entropy in the universe is inevitable as expressed in the Second Law, but this very increase is the necessary requirement for the emergence and maintenance of self-organized systems. The debt of self-organizing systems to "chaos" is the environmental increase in entropy. As we shall see sustainable societal self-organization on the planet Earth is only limited by the low-entropy solar flux, a limit with no practical consequences far into the future, with the entropic debt paid as the heat flux to space, the ultimate heat sink. This future, I argue, is only achievable by the contingent outcome of global red-green struggle.

Given the mineral and fossil fuels reserves of the Earth's crust, the "economic system is... doomed to "run down" as the low entropy material resources on earth are dissipated and become unavailable" (Burkett, 2005, 135, quoting Georgescu-Roegen). We do not need a fallacious fourth law to tell us this, the first and second laws provide sufficient explanation. Without the use of incoming solar radiation, this system will ultimately run out of available energy to do work. It is important to point out that even without the use of incoming solar radiation as a prime source of energy (aside from the low efficiency collection by photosynthesis, the basis of agriculture), this system is not <u>isolated</u> since waste heat is dissipated, ultimately radiated into space. Nuclear energy, even fusion power will only postpone this ultimate fate in a real economy limited to the terrestrial environment since this energy source utilizes the finite reserves of fissionable (or, in the future, fusionable) raw material. The solar fusion reactor 93 million miles away is the true sustainable alternative.

Thus the inescapable flaw of the fourth law is its neglect of the possible flow of energy into/out of the system which is defined as closed but not isolated. By converting low entropy, high temperature energy (solar radiation) to high entropy, low temperature heat, work can be produced to recycle indefinitely (footnote 2). A caveat: indefinitely does not mean "eternally" (even protons may have a finite half-life). To get concrete about this issue, the relevant time scale is hundreds, even millions of years, not eternity. Moreover, we should be considering the urgent prospect of solarizing and demilitarizing human society in the 21st century, not in the distant future, when humanity will plausibly expand outward in our solar system and even further into the galaxy if it survives the present epoch of destructive capital reproduction and future challenges.

Interestingly, in one text Georgescu-Roegen (1976, 8) incorrectly defines “closed” as entailing no exchange of matter or energy with [the] environment (recall that in thermodynamics this is defined as an “isolated” system, not a “closed” system); he still maintained that according to the second law matter along with energy is subject to irrevocable dissipation. This confusion may be linked to his pessimistic view on harnessing solar energy since the latter is the relevant energy flux to consider for the closed but not isolated system containing economic activity on the earth’s surface. Thus, immediately following his formulation of the fourth law in his 1980 text we find his argument that there is no immediate prospect of solar energy (high efficiency) going from feasible to viable, i.e., escaping from its perpetual status as a parasite on fossil fuels, the dominant contemporary energy source. Parenthetically, I found no evidence that Georgescu-Roegen ever explicitly corrected himself by acknowledging his definition of closed systems in this paper (Georgescu-Roegen 1976) was wrong.

But Burkett claims that the concept of unavailable matter, “the inevitability of friction, corrosion and decomposition” transcending energy reductionism is critical to Georgescu-Roegen’s insight. Therefore, Burkett argues that since the “earth is open to massive solar energy inflows but basically closed materially, it is not surprising that low-entropy matter, not energy, emerges most clearly as the ultimate constraint on human production” (Burkett, 2005, 119-120). I welcome Burkett’s implied rejection of Georgescu-Roegen’s views on solar viability. But his argument regarding the implications of “unavailable matter” is highly problematic, recognizing that it is a partial retreat from the strong version of the fourth law. On what time scale? What are the real and potential fluxes of low entropy solar energy that can reclaim this dissipated matter? Just what determines the “unavailability” of high entropy matter? Does this alleged constraint imply that near future migration to the moon or asteroid Belt is necessary? Is waste heat a critical concern with respect to the utilization of solar energy? And finally is this spectre of “unavailable matter” really relevant to a future solarized physical economy? My short answer to each of the previous three questions is: no.

What is the ultimate limit to global energy consumption? Presently the global anthropogenic (human-created) energy flux is equal to 0.03% of solar flux to land. Or, to put it another way, humanity currently uses an amount of energy, mostly from fossil fuels, equivalent to 0.03% of the solar energy reaching the land surface of earth. Hence tapping this solar flux has a huge potential as the energy basis of a solar utopia, with much smaller impacts on global ecology than the present unsustainable reliance on fossil fuels and nuclear power (Schwartzman, 1996). Thus, for a solar energy source, the waste heat flux back into space is to a very good first approximation *not* incremental to the natural infrared flux from the Earth’s surface, at least until such time as human energy demand increases many hundreds of times. This is precisely the same argument made by Kaberger and Mansson (2001) referenced but unfortunately not addressed in Burkett’s paper. Of course, I am not claiming that the first basis for human civilization, low efficiency biomass energy, can be the basis of this solarized economy. Only high-efficiency solar energy can do this. The conflation of the two is common in Neo-Malthusian treatment (e.g., Huesemann, 2001, 2003).

**Recycling**

Now, more specifically on the possibility of "complete" recycling in an open system, Burkett’s discussion of this issue (Burkett, 2005, 132) lacks sufficient concreteness with respect to a real physical economy on the earth’s surface, consistent with Georgescu-Roegen and Daly’s abstract treatment. In practical terms, 100% recycling efficiency is not required (see Kaberger and Mansson's (2001) illuminating discussion). Given the possibilities of a future dematerialized solar economy, with a lower throughput than now, and of course recognizing that current information technology is not really dematerialized under current capital reproduction, as Burkett rightfully argues, (2005,135), the huge solar flux is again the basis of any ultimate limit to practical recycling on the earth's surface, and not the entropic flux of waste heat. The latter would be dissipated anyway by the absorption of solar energy on a land surface (with an albedo, i.e., reflectivity, of about 0.3-0.4, with 0 being perfectly absorbing and 1 being perfectly reflecting (like an ideal white surface). Under these conditions, the "tremendous increase in the entropy of the environment' or the “adverse material effects of waste heat on eco-systems” resulting from recycling (Burkett, 2005,132-133) is an illusion for a solarized economy as Kaberger and Mansson (2001) show. Unfortunately, Burkett's discussion of the case made for the plausibility of total recycling in an industrial society (citing Ayres, 1999) does not confront the qualitative difference between a solarized and a depletable-energy-based economy.

Further unclarity is found in Burkett's quotation from Georgescu-Roegen "at the macro-level no practical procedure exists for converting energy into matter or matter of whatever form to energy". It is not clear "whatever form" means. In a footnote Burkett cites Daly (Burkett, 2005, 120; Daly, 1991 (a different printing, 1992 is cited by Burkett) in support. In this reference Daly says "Although we can turn matter into energy, we have no means for turning energy into matter on a significant scale". Daly is clearly referring to nuclear reactions, where mass to energy conversion is small but measurable, unlike chemical reactions where the conversion likewise occurs but is infinitesimal.

Burkett critiques energy reductionism in his citation of Georgescu-Roegen (Burkett, 2005, e.g., 121, Footnote 14). Is it energy reductionism to uphold the relevancy of the second law, i.e., entropy must be considered besides energy, entropy in its full quantitative and qualitative aspects (see discussion of the entropy of mixing and its relevancy to recycling and pollution in Schwartzman, 1996). Ignoring the second law is indeed energy reductionism. The issue of friction and dispersal of matter in anthropogenic cycles has energetic, biogeochemical and social qualitative aspects, which some critics of Georgescu-Roegen take seriously, but that does not make the "fourth law" any more valid. Friction equals waste heat; dispersal of matter can be radically reduced depending on the physical design of the process of production/consumption and, of course, energy source. Two of Georgescu-Roegen's examples of "unavailable matter" arising from the inevitable friction inherent in any physical process are rust and broken glass (Georgescu-Roegen, 1986). So we are to believe that even with available energy these wastes cannot be efficiently turned back into iron and glass bottles respectively!

If the reader will indulge me, I will now make a personal observation to illustrate a point about recycling. My now deceased father spent 40 years as a diamond setter on the Bowery in lower Manhattan. He collected the filings of platinum and gold in a metal tray below his workspace. He and his brothers then sold the filings to be remelted. They could have thrown them in the trash, to end up dispersed in a landfill (still recoverable but requiring more energy). The energy difference in recycling and its potential impacts of the alternatives are obvious. Industrial design and environmental policy are critical aspects of the efficiency and energy requirements of recycling and waste production. We have much to learn from natural ecosystems in this respect. The concept of cycling ratio (Volk, 1998), the ratio between the flow within an ecological cycle and the flow into/out of this cycle at steady-state, can provide some insight into the potential efficiencies of future solar industrial production/consumption. The very high cycling ratios achieved by ecosystems for several elements (e.g., potassium) with relatively small fluxes into the biosphere suggest that natural systems are useful models for industrial ecology and a sustainable future (see Ho and Ulanowicz, 2005, for further insights along these lines). Here a fruitful dialogue and collaboration should occur between ecological Marxists, ecological economists, ecologists and biogeochemists, among others.

## Is Solar Communism Realizable Or Just Another Infantile Disorder?

The core of the red-green project is to effect an ecosocialist transition from global capitalism to "solar communism", my name for a future global society that will realize an updated version of Marx's guiding principle for his vision of communism, namely "from each according to her ability, to each according to her needs", where "her" refers to humans and nature (ecosystems) (Schwartzman, 1996). I urge that concrete visions of communist utopia should now be discussed and represented by political movements that challenge the global rule of capital. This envisioning should of course be a work in progress, continually revised with input from both the scientific-technological and political communities. If there is "another world possible" let's begin describing concretely how it will function and begin creating embryos of the future as global class struggle unfolds to achieve its full reality.

The material prerequisites for solar communism include: 1) a global high efficiency solar energy infrastructure, replacing fossil fuels and nuclear energy; 2) application of the containment and precautionary principles to environmental policy (including industrial ecology, organic agriculture centered around and in green cities); 3) progressive dematerialization of technology, global availability of state-of-the-art information technology;
4) increase of human population density centered in green cities, elimination of sprawl leaving extensive biospheric reserves, managed to preserve biodiversity.

Radical political and economic changes are, of course, necessary to realize these material prerequisites (Schwartzman, 2005), a challenge that is now a focus of intense investigation and debate by scholars and activists globally.

The transition to energy-limited (not entropy-limited!) solar communism must proceed from entropy-limited capitalism through ecosocialism (Schwartzman, 1996). I think that "solar capitalism" is an illusionary prospect because the level of red and green struggle required to solarize global capitalism will likely result in ecosocialist transition. While individual capitalist economies may solarize, the dominant role of the "nuclear military fossil fuel industrial complex" in global capitalist reproduction makes its termination both an essential requirement for and likely a direct path to ecosocialist transition on a global scale.

Is ecosocialist transition to solar communism an achievable goal in this the 21st century, or is this simply wishful thinking, an example of an infantile disorder as identified in Lenin's Left Wing Communism? Aside from the formidable political challenges, are the claimed material prerequisites realizable? Two material prerequisites are arguably paramount: the creation of a solar-based energy infrastructure, and an agroecology sufficient to support the global human population while significantly reducing negative environmental and ecological impacts. The practicality of creating a global solar infrastructure with even existing technologies by mid century is now plausibly argued (e.g., Leggett, 2006; Scheer, 2002, 2007; Bradford, 2006; Shinnar and Citro, 2006, for the U.S.). The energy and material requirements for this transition are considerable but not limited by the available fossil fuel reserves; nor are the negative impacts from this necessary parasitism on the existing energy base significant, relative to the continued reliance on a fossil fuel base. One example is a current plan to create a concentrated solar power infrastructure in the Sahara, which would meet the entire present demand for electricity in Europe and simultaneously provide a large increase in power availability for North Africa, with a radical reduction in carbon emissions, by 2050, at a lower cost per kwh than present market costs for electricity production (footnote 3). Demilitarization will free up vast human and material resources necessary for this transition. If this prospect is unthinkable on the time frame necessary to avoid the likely catastrophes of global warming impacts, then so is any meaningful progress for humanity in this century.

And as for the second big challenge, can the global population be fed without the concomitant negative impacts of industrial agriculture? To be sure, the world and especially urban areas in countries of the South are overpopulated, but only in the context of the carrying capacity of the present political economy in this world of extreme inequalities and not the alleged carrying capacity of the biosphere. Mike Davis eloquently describes the overpopulated cities of the South, bursting with poor residents driven from rural areas (Davis, 2006); this results from the social impacts of the so-called green revolution (Boucher, 1999) as well as structural adjustment programs imposed by the IMF. But other regions are actually now under- populated, such as rural areas in countries of sub-Saharan Africa, devastated by AIDS, with population size arguably too low to restore and maintain sustainable agricultural production.

Human population size and relative overpopulation are not the fundamental drivers of global inequalities and widespread misery; they are, rather, symptoms of the unsustainability of this world dominated by capital reproduction takes priority over the needs of humanity and nature. Even now there is still enough food produced globally, both in calories and nutritional content, to potentially feed everyone (Boucher,1999), although this mode of production has huge negative impacts on people and nature. Hunger and malnutrition are the results of existing political economy not any real shortage of food. But can agroecology still feed the world's population without the well-known negative impacts of industrial agriculture? There is a very good case that it can, even in preferred synchronicity with the process of solarization (Badgley et al., in press; Ho and Ching, 2003; Pimentel et al., 2005; Vasilikiotis, 2005).

## Conclusion

In the interests of promoting more dialogue between ecological Marxists and ecological economists we need principled and clear arguments that are firmly rested on real science, in this case thermodynamics. The appropriation of misleading entropy concepts by Marxists is particularly unhelpful, since Marxist theory should be a guide for red-green political practice.

## Footnotes

1 E.g., Ayres, 1997, 1998, 1999; Kaberger and Mansson, 2001; Fleissner and Hofkirchner, 1997; Baumgartner, 2002, 2003, 2005; Cleveland, 1999; Cleveland and Ruth, 1997; Craig, 2001; Gillett, 2006; Rothman 1989.

2 See e.g., Bianciardi et al., 1993. Burkett (2005,132) cites this paper's additional claim that complete recycling would "involve a tremendous increase in the entropy of the environment, which would not be sustainable for the biosphere" . However, this outcome would not apply in any practical sense to recycling with a solar energy source, as I will shortly show.

3 The Trans-Mediterranean Renewable Energy Cooperation (TREC) Project:
http://www.trecers.net/index.html
http://www.mng.org.uk/green_house/renewable_energy/csp.htm

## References


- Atkins, Peter W. 1984. The Second Law. New York: Scientific American Books.
- Attarian, John. 2005. 'The Steady-State Economy: What it is, why we need It', NPG Forum, NPG-103, March, 1-8. http://www.npg.org/forum_series/steadystate.pdf

- Ayres, Robert U. 1997. 'Comments on Georgescu-Roegen', Ecological Economics, 22, 3: 285-287.
- ______________. 1998. 'Eco-Thermodynamics: Economics and the Second Law', Ecological Economics, 26, 2: 1890-209.
- ______________.1999. 'The Second Law, the Fourth Law, Recycling and Limits to Growth', Ecological Economics, 29, 3: 473-83.
- Badgley, Catherine, Jeremy Moghtader, Eileen Quintero, Emily Zakem, M. Jahi Chappell, Katia Aviles-Vázquez, Andrea Samulon, and Ivette Perfecto. "Can organic agriculture feed the world?" Renewable Agriculture and Food Systems. In press.
- Baumgartner, Stefan. 2002. Thermodynamics of Waste Generation, in Ecological Economics, edited by K. Bisson and J. Proops, Cheltenham, UK: Edward Elgar.
- _________________. 2003. Entropy, Internet Encyclopaedia of Ecological Economics, International Society for Ecological Economics, http://www.ecoeco.org/publica/encyc.htm
- __________________. 2005. "Thermodynamic Models." Pp. 102-129 in John L.R. Proops and Paul Safonov eds., Modelling in Ecological Economics, Cheltenham, UK, and Northampton, MA, USA: Edward Elgar.
- Bianciardi, Carlo, Tiezzi, Enzo and Sergio Ulgiati. 1993. 'Complete recycling of matter in the frameworks of physics, biology and ecological economics', Ecological Economics 8:1, 1-5.
- Boucher, D., ed. 1999. The Paradox of Plenty, Oakland, California: Food First Books.
- Boucher, Doug, Barclay, Bill, Lichtenberg, Erik, Middendorf, George, and David Schwartzman. 1993. Review of For the Common Good. Capitalism Nature Socialism 4 :3, 129-135.
- Boucher, Doug, David Schwartzman, David, Jane Zara, and Peter Caplan. 2003. "Another look at the end of the world." Capitalism Nature Socialism. 14: 3, 123-131.
- Bradford, Travis. 2006. Solar Revolution: The Economic Transformation of the Global Energy Industry. Cambridge, Massachusetts: The MIT Press.
- Burkett, Paul. 1998. 'A Critique of Neo-Malthusian Marxism: Society, Nature, and Population', Historical Materialism, 2, 1: 118-42.
- ____________. 2003. The Value Problem in Ecological Economics, Lessons from the Physiocrats and Marx, Organization & Environment,16, No. 2: 137-167.
- ____________. 2005. 'Entropy in Ecological Economics: A Marxist Intervention', Historical Materialism, 13, 1: 117-52.
- Burkett, Paul. 2006. Marxism and Ecological Economics. Leiden: Brill.
- Campaign for Political Ecology. nd. http://eco.gn.apc.org/
- Cleveland, Cutler J. 1999. "Biophysical Economics: From Physiocracy to Ecological Economics and Industrial Ecology." Pp. 125-159 in Bioeconomics and Sustainability: Essays in Honor of Nicholas Georgescu-Roegen, edited by Kozo Mayumi and John M. Gowdy. Cheltenham: Edward Elgar Publishing,.
- Cleveland, Cutler J. and Matthias Ruth. 1997. "When, Where, and By How Much Do Biophysical Limits Constrain the Economic Process? A survey of Nicholas Georgescu-Roegen's Contribution to Ecological Economics." Ecological Economics, 22, 203-223.
- Cohen, Joel E. 1995. How Many People Can the Earth Support? New York: W.W. Norton,
- Costanza, Robert, Cumberland, John H., Daly, Herman, Goodland, Robert and Richard Norgaard, 1997 An Introduction to Ecological Economics. Boca Raton, Florida: CRC Press.
- Craig, Paul P. 2001. "Energy limits on recycling." Ecological Economics. 36, 373–384.

- Czech, Brian, 2000. Shoveling Fuel for a Runaway Train: Errant Economists, Shameful Spenders, and a Plan to Stop them All. Berkeley, California: University of California Press.
- Czech, Brian and Herman E. Daly. 2004. "In My Opinion: The Steady State Economy- What It Is, Entails, and Connotes." Wildlife Society Bulletin, 32: 2, 598-605.
- Daly, Herman E. 1991. Steady-State Economics. 2nd edition. Washington, DC: Island Press.
- Davis, Mike 2006 Planet of Slums. London: Verso.
- Fleissner, Peter and Wolfgang Hofkirchner. 1997. "Entropy and its Implications for Sustainability." Pp.147-155 in Implications and Applications of Bioeconomics. Proceedings of the Second International Conference of the E.A.B.S., Palma de Mallorca. 1994. Edited by Iosif C. Dragan, M.C. Demetrescu, and Eberhard K. Seifert. Milan, Italy: Edizioni Nagard.
- Foster, John Bellamy and Paul Burkett. 2004. Ecological Economics and Classical Marxism, The "Podolinsky Business" Reconsidered., Organization & Environment, Vol. 17, No. 1: 32-60.
- Georgescu-Roegen, Nicholas. 1971, The Entropy Law and the Economic Process. Cambridge: Harvard University Press.
- ________________________.1976. Energy and Economic Myths. New York: Pergamon Press.
- ________________________.1980. 'Afterword', in Rifkin, Jeremy, Entropy. Revised edition 1989, New York: Bantam Books.
- ________________________1981. 'Energy, Matter, and Economic Valuation: Where Do We Stand?' in Energy, Economics, and the Environment. Edited by .Herman E. Daly and Alvaro F. Umana, AAAS Selected Symposium 64. Boulder, Colorado: Westview Press.
- ________________________.1986. 'The entropy law and the economic process in retrospect', Eastern Economic Journal 12, 1: 3-25.
- Gillett, Stephen L. 2006, "Entropy and its misuse, I. Energy, free and otherwise." Ecological Economics, 56, 58– 70.
- Gillott,, John and Manjit Kumar. 1997. Science and the Retreat from Reason. New York: Monthly Review Press.
- Hanson, Jay. 2001. Die-off Energy Synopsis http://www.dieoff.com/synopsis.htm
- Hardin, Garrett J. 1993. Living within limits : ecology, economics, and population taboos. New York: Oxford University Press.
- Harvey, Fiona. 2006. The heat is on: how global warming could suddenly tip over and ignite calamity. Financial Times September 15. http://www.ft.com/cms/s/b265a2b4-4456-11db-8965-0000779e2340.html
- Ho, M-W. and L.L. Ching. 2003. The Case for a GM-free sustainable world. Independent Science Panel. Ho, M-W. and Lim Li Ching. 2003. "The Case for a GM-free Sustainable World." Independent Science Panel. http://www.indsp.org/A%20GM-Free%20Sustainable%20World.pdf
- Ho, Mae-Wan and Robert Ulanowicz. 2005. 'Sustainable systems as organisms?', BioSystems, 82: 39-51.
- Huesemann, Michael H. 2001. Can pollution problems be effectively solved by environmental science and technology? An analysis of critical limitations, Ecological Economics, 37: 271-87.
- ______________. 2003. The limits of technological solutions to sustainable development', Clean Technology Environmental Policy, 21-34 (online).
- Ilyenkov, Evald. 1982. The Dialectics of the Abstract and the Concrete in Marx's Capital. Moscow: Progress Publishers.

- Kaberger, Tomas and Bengt Mansson. 2001. 'Entropy and Economic Processes – Physics Perspectives' Ecological Economics, 36,1: 165-79.
- Kovel, Joel. 2002. The Enemy of Nature: The End of Capitalism or the End of the World? New York: Zed Books.
- Leggett, Jeremy, 2006 Half Gone, Oil, Gas, Hot Air and the Global Energy Crisis. London: Portobello Books.
- Lovelock, James. 2006. The Revenge of Gaia: Why the Earth is Fighting Back — And How We Can Still Save Humanity. New York: Basic Books.
- Martinez-Alier, Juan. 1987. Ecological Economic. Cambridge, Massachusetts: Basil Blackwell.
- Mayumi, Kozo and Mario Giampietro. 2004. 'Entropy in Ecological Economics', in Modelling in Ecological Economics, edited by John L.R. Proops, and Paul Safonov Cheltenham, UK: Edward Elgar.
- Milliken, Mary. 2006. World has 10-Year Window to Act on Climate Warming - NASA Expert. September 14. Reuters, http://www.commondreams.org/headlines06/0914-01.htm
- Mims III, I. M. 2006. Meeting Doctor Doom. The Citizen Scientist Mims III, Forrest M. 2006. "Meeting Doctor Doom." The Citizen Scientist. http://www.sas.org/tcs/weeklyIssues_2006/2006-04-07/feature1p/index.html
- Pimentel, David. 2006. "Overpopulation and Sustainability." Frontiers in Ecology and the Environment, 4, 155.
- Pimentel, David, Hepperly, Paul, Hanson, James, Douds, David, and Rita Seidel. 2005. "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems." BioScience, 55, 573-582.
- Pimentel, David and Marcia Pimentel. 2006. "Global Environmental Resources Versus World Population Growth". Ecological Economics, 59, 195-198.
- Rapley, Chris. 2006. Earth is too crowded for Utopia. BBC VIEWPOINT http://news.bbc.co.uk/2/hi/science/nature/4584572.stm
- Revkin, Andrew C. 2006. A Conversation With James E. Lovelock, Updating Prescriptions for Avoiding Worldwide Catastrophe. September 12, New York Times, D2.
- Rifkin, Jeremy. 1980. Entropy. New York:Viking Press (1989. Revised edition. New York: Bantam Books).
- Rothman,Tony. 1989. Science a la Mode. Princeton. New Jersey: Princeton University Press.
- Scheer, Hermann. 2002. The Solar Economy: Renewable Energy for a Sustainable Global Future. London: Earthscan.
- __________________ 2007. Energy Autonomy: The Economic, Social and Technological Case for Renewable Energy. London: Earthscan.
- Schwartzman, David. 1996. 'Solar Communism', Science & Society, 60, 3: 307-31.
    - Online: http://www.redandgreen.org/Documents/Solar_Communism.htm
- _______________.1999, 2002. Life, Temperature, and the Earth: The Self-Organizing Biosphere. New York: Columbia University Press.
- _______________. 2005. Our Future Solar Utopia Revisited (abstract and talk), Technonatures session, The 37th World Congress of the International Institute of Sociology in Stockholm, July 5-9, 2005. http://www.redandgreen.org/Documents/Our_Future_Solar_Utopia_Revisited.htm
- Shinnar, Reuel and Francesco Citro. 2006. ENERGY: Enhanced: A Road Map to U.S. Decarbonization. Science 313,1243 – 1244.

- Vasilikiotis, Christos. 2005. Can Organic Farming "Feed the World"? http://www.cnr.berkeley.edu/~christos/articles/cv_organic_farming.html
- Volk, Tyler. 1998. Gaia's Body: Toward a Physiology of Earth. New York: Springer-Verlag.

David Schwartzman
Professor
Department of Biology
Howard University
Washington, DC 20059