Toward a Sustainable World Economy

by

William E. Rees, PhD, FRSC
University of British Columbia
School of Community and Regional Planning
6333 Memorial Road
Vancouver, BC, CANADA
V6N 1T2

Institute for New Economic Thinking Annual Conference
– *Crisis and Renewal: International Political Economy at the Crossroads* –
Mount Washington Hotel
Bretton Woods, NH, USA
8-11 April, 2011

Economic Paradigms - Social Constructs All

> What the scientist's and the lunatic's theories have in common is that both belong to conjectural knowledge. But some conjectures are much better than others… (Popper 1972).

> You may say, if you wish, that all 'reality' is a social construction, but you cannot deny that some constructions are 'truer' than others. They are not 'truer' because they are privileged, they [become] privileged because they are 'truer.' (Postman 1999, 76)

All cultural narratives, worldviews, religious doctrines, political ideologies, and academic paradigms are 'social constructs.' They are products of the human mind massaged or polished by social discourse and elevated to the status of *received wisdom* by agreement among members of the social group who are creating the construct (see Berger and Luckmann 1966).

In some contexts, people more or less automatically and passively acquire their allegiance to important social constructs. For example, we gradually adopt the fundamental beliefs, values, assumptions, and behavioral norms of our 'tribe' or society simply by growing up in a particular cultural milieu. In other situations—in church or in school, for example—we are essentially the captives of social institutions that exist explicitly to indoctrinate their 'clients' with the accepted way of seeing the world. In any event, by the time most people have reached mature adulthood they will have accepted their culture's overall 'narrative' and will subscribe, consciously or not, to any number of subsidiary religious, political, social and disciplinary paradigms.

It is important to underscore that, although it masquerades as 'reality' in our consciousness, all formal 'knowledge' is, in fact, socially constructed. Some constructs are *entirely* made up—there is no corresponding structure in the natural world for 'civil rights' or 'communism', for example. These well-known concepts were birthed and given legs entirely through words and social discourse. Other socially-constructed frameworks have been erected specifically to describe corresponding real-world phenomena. For example, everyone here will agree that 'the economy' is that set of activities central to the production, distribution and consumption of goods and services in a specified region or country. Nevertheless, such activities exist in all societies whether or not the people have any formal concept of 'the economy'

Will the real economy please stand up

As implied above, there are many different ways of conceiving the 'appropriate' structure and function of the economy. Each alternative reflects its followers' unique set of socially-constructed beliefs, values and assumptions about the structure of the economy, how it relates to other systems and how economic activities should be conducted and regulated to serve particular specified ends. Alternative economic paradigms may differ radically—entities or activities that are given prominence in one paradigm may be marginalized or omitted altogether from another. Things can get complicated—an economic paradigm is a socially-constructed model that may contain other models that are themselves socially constructed!

Despite being mere constructs, ideologies and paradigms are extremely powerful. They are perceptual filters through which we interpret all new data and information; while essentially subjective, they constitute our perceived ‘reality’ and determine how people ‘act out’ in the real world. It is therefore important to emphasize that: a) no economic paradigm can ever be more than a partial representation of external reality, and; b) while all paradigms belong in the domain of conjectural knowledge, not all conjectures are created equal. Some conjectures are demonstrably better than others, particularly in terms of how well they represent the real world. “Conjectures are our trial balloons, and we test them by criticizing them and by trying to replace them, by trying to show that there can be better or worse conjectures, and that they can be improved upon”… “So long as a theory stands up to the severest tests we can design, it is accepted; if it does not, it is rejected” (Popper 1972).

Table 1 (attached) contrasts two competing economic visions, the neo-liberal expansionist paradigm (a corrupted version of which prevails in the world today) and the ecological economics vision which is struggling to emerge from the on-going sustainability discourse. The table shows that from their epistemological roots to their policy prescriptions, these two ‘pre-analytic visions’ of the economy reflect vastly different perceptions of economic and biophysical reality, particularly in terms of how the economy functions in relation to the rest of the ecosphere. As Coase (1997) has opined, “Existing economics is a theoretical [meaning mathematical] system which floats in the air and which bears little relation to what happens in the real world”. Ecological economics was therefore born out of necessity, a concerted effort by liberated economists, ecologists and political scientists to bring the economy back to solid ground.

The purpose of this paper is to make the case that the neo-liberal vision, always crude in its representation of both *Homo economicus* and the economic system itself, is not only failing on its own terms but has actually become an ecological hazard to the future of civilization. A sustainable alternative is needed. Canadian environmental journalist and author, Andrew Nikiforuk describes our dilemma this way:

> Let’s face it: *Homo economicus* is one hell of an over-achiever. He has invaded more than three-quarters of the globe’s surface and monopolized nearly half of all plant life to help make dinner. He has netted most of the ocean’s fish and will soon eat his way through the world’s last great apes. For good measure, he has fouled most of the world’s rivers. And his gluttonous appetites have started a wave of extinctions that could trigger the demise of 25 percent of the world’s creatures within 50 years. The more godlike he becomes the less godly *Homo economicus* behaves (Nikiforuk 2006).

A major problem with neoliberal economics that its foundational models are based on ideas borrowed from Newtonian analytic mechanics (an excellent paradigm for the design of automobile engines), have a naively constricted view of actual human economic and social behaviour, carry reductionist logic to extremes by all but excluding reference to the rest of biophysical reality and reflect arrogant certainty in their prescriptions. By contrast, while by no means perfect, ecological economics is explicitly grounded in complex systems theory and far-from-equilibrium thermodynamics (necessary to describe real-world economic-, social- and eco-systems behavior), adopts a much more generous view of human nature, perceives the economy as a integral component of the ecosphere and accepts the need to adapt the economy to irreducible systemic uncertainty (Table 1). Keep in mind that every economic system is, in effect, an experiment that necessarily tests its fundamental propositions against the reality within which it is embedded. When a model fails the 'severest tests we can design' it should be modified or rejected and replaced outright. Given the current scale of economic activity, a faulty economic paradigm has the potential not only to undermine the world economy but also to wreck the biophysical basis of its own existence. The question is, based on the evidence, should we be considering rejecting the neo-liberal 'conjecture' and replacing it with (at least for starters) something resembling the ecological economics framework?

The cultural roots of bio-economic failure

And what is the evidence that the growth paradigm is failing? The world community is facing an unprecedented global ecological crisis. Anthropogenic greenhouse gases are accumulating in the atmosphere and resultant climate change is a fact; 75% of the world's fish stocks are over-exploited; ocean dead (anoxic) zones are spreading; deserts are expanding; tropical deforestation wreaks havoc with biodiversity; half the land area of Earth has been appropriated for human purposes; soil degradation and rising energy costs threaten future food production; water scarcity is an urgent and growing problem for millions of people, particularly in densely populated poor countries—the list goes on. While each of these 'problems' is serious in itself, all are merely symptoms of a greater systemic malaise—*gross human ecological dysfunction*. Like all other species, *H. sapiens* has an innate tendency to expand to occupy all accessible habitat and to use all available resources (in the case of humans, 'availability' is defined by technology) (Rees 2010). These natural predispositions are currently being reinforced by a cultural and economic narrative based on the myth of continuous progress and perpetual economic growth. The human enterprise is therefore breaching biophysical limits and destabilizing critical life-support systems on this finite planet (WWF 2008, 2010; Rockström et al. 2009). No individual symptom of the resultant dysfunction can be solved without addressing this overall syndrome.

One source of eco-dysfunction is techno-industrial society's social construction of man-in-nature. The citizens of modern nations tend to perceive 'the environment' as separate from the human enterprise, as a distant 'other' that serves primarily as resource trove and physical backdrop for human affairs.[1] Consistent with this perception, the ethical foundation for human relationships with 'the environment' in industrial societies is *utilitarian, anthropocentric* and *instrumentalist*. It is utilitarian in that other species matter only to the extent that people value them; anthropocentric in that humans are assigning the values; and instrumental in that all of nature is regarded as a resource trove that exists strictly for human satisfaction (Randall 1988). Certainly there is nothing about the distant 'other' that might constrain human ambitions, including the myth of continuous economic growth.

[1] The psychological alienation of humans from nature has deep cultural roots traceable at least to ancient Greece; its modern expression flowered during the Enlightenment with the articulation of what we now know as 'Cartesian dualism'; and it has only recently found its most ebullient (and environmentally violent) expression in the on-going scientific/industrial revolution.

Indeed, the divorce of humans from nature is virtually complete when it comes to the neo-liberal market economics that dominates global development thinking today. “Something strange happened to economics about a century ago. In moving from classical to neo-classical economics… economists expunged land — or natural resources” from their theorizing (Wolf 2010). Land and resources [read ‘the ecosphere and natural processes’] were quietly dropped from mainstream production functions as capital (including finance capital) and knowledge came to be perceived as the principal sources of wealth and drivers of growth.[2]

This cognitive fiction has been maintained historically because: 1) the undervaluation of nature relative to other factors of production (no one pays the earth for the resources we extract) means that in ‘advanced’ economies land and resources *per se* often contribute only marginally to GDP and; 2) technology has succeeded (until recently) both in keeping the costs of extracting raw materials low and in finding substitutes for some resources that have become scarce (e.g., coal substituted for wood as the primary fuel of the industrial revolution; fish-farms increasingly substitute for wild fish-stocks). Bottom line? Most contemporary economic models still float free from biophysical reality, blind to the energy and material flows essential for human existence, to the state of vital natural capital stocks, and to the complex dynamics of the ecosystems that produce them (see Christensen 1991).

The ethereal economy

> All thinking about the world involves a degree of abstraction. Economics has taken this principle further than any other social science (Wolf 2010).

This is no trivial perceptual lapse. The traditional starting point for neoliberal economic analysis is the ‘circular flow of exchange value’, typically portrayed in standard texts as “a pendulum movement between production and consumption within a completely closed system” (Georgescu-Roegen 1971a) . This model is totally abstracted from biophysical context (Table 1). Value embodied in goods and services flows from firms to households in exchange for spending by households (national product). A supposedly equal value, represented by factors of production (labour, knowledge, finance capital), flows back to firms from households in exchange for wages, rents, dividend, etc., (national income). Some economists describe this stripped-down economy as a form of perpetual motion machine that generates a “flow of output that is circular, self-renewing, self-feeding” (Heilbroner and Thurow 1981). Indeed, the circular flows model makes no reference whatever to the energy and resources required to produce the goods and to generate the income flows that the model does represent. Thus, in economists’ minds “…the circular flow is an isolated, self-renewing system with no inlets or outlets, no possible point of contact with anything outside itself” (Daly 1991, p.196). Such a model can neither anticipate nor explain resource scarcity or pollution problems. Considering the economic process as a circular flow without considering the unidirectional throughput of energy and matter is akin to studying physiology in terms of the circulatory system with no reference to the

[2] This will seems odd to non-economists, because most people still participate in ‘the economy’ to acquire the material basis of their own existence.

digestive track. One might as well ask engineering students to fathom how "a car can run on its own exhaust" or biology students to accept that "an organism can metabolize its own excretia" (Daly 1991, p.197).

The emergence of major ecological problems in the 1960s forced economists to adapt their thinking and at least acknowledge the existence of something outside the economy. Figure 1 shows the still-prevailing vision of the economy-environment relationship from the perspective of mainstream *environmental* economics.[3] Note that there are still two separate systems. And while the economy may draw on the environmental 'other' for resources but this is not really a critical relationship—many economists believe that, abetted by free-market incentives, human ingenuity will find technological substitutes for any product of nature that humans may deplete.[4] Similarly, we can solve problems arising from pollution (the over-filling of waste sinks) by 'internalizing the externalities'—putting a market price on waste sink functions. (Consider contemporary efforts around the world to put an effective price on carbon emissions.)

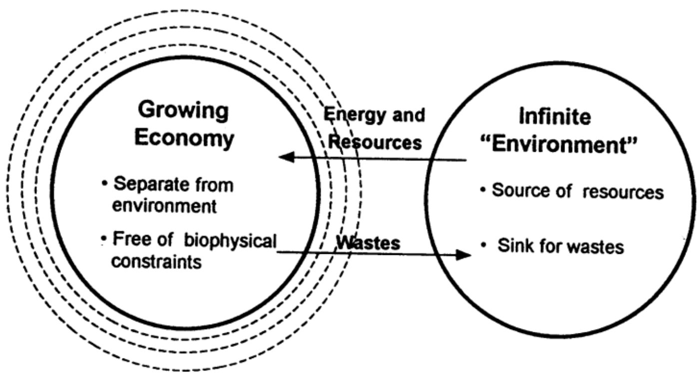

Figure 1: Growth-based neoliberal economics treats the economy as a separate, open, growing, quasi-independent system lacking any important connectedness to an inanimate 'environment'.

Consistent with this perspective, some economists persist in their attempts to unshackle the economy from its annoying ties to the environment. Using abstract money-based models, they suggest that the human enterprise is actually 'dematerializing', that economic activities are 'decoupling' from the natural world.[5] The critical implication is that the human enterprise should be able to continue consuming and growing unaffected by resource depletion or changes in the state of the ecosphere. In effect, then, mainstream economic theory dissolves ecological constraints—or takes 'the environment' to be limitless—thus freeing the economy for perpetual growth (Table 1). This is one reason why politicians and policy makers rarely hesitate to 'trade off'

[3] *Environmental* economics is not to be confused with *ecological* economics. The former is simply an extension of the conventional analysis better to account for the costs, prices and trade-offs associated with so-called environmental goods and services. *Ecological* economics (see following section) more completely redefines the environment-economy relationship.
[4] Nobel Lauriat economist Robert Solow put the case as follows: "If it is very easy to substitute other factors for natural resources, then... The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe" (Solow 1974).
[5] In some developed countries, GDP per capita is growing more rapidly than energy and material consumption suggesting that wealth creation is becoming less dependent on resources (i.e, production is becoming more efficient, resource productivity is increasing). Some analysts also believe that environmental problems abate as economies shift from resource exploitation and manufacturing to service industries. All such apparent 'decoupling' weakens if we consider traded flows and actual material *consumption* (rather than dollar income) per capita.

ecological concerns for economic gain (with a generally willing populace cheering from the bleachers). Economic growth has thus become the strongest plank in the policy platforms of most governments around the world for at least the last half century (see Victor 2008).

Biophysical Reality: The human enterprise as 'dissipative structure'

Any effort to articulate a 'truer' alternative construct of humankind-environment relationships must include a sound understanding of the biophysical laws underlying those relationships. One of the most fruitful ways of conceptually reconnecting people to nature starts with contemporary interpretations of 'far-from-equilibrium' thermodynamics. The starting point for this approach is the second law of thermodynamics, the entropy law.

In its simplest form, the second law states that any spontaneous change in an isolated system—a system that can exchange neither energy nor material with its environment—increases the system's 'entropy'. This is a technical way of stating that things naturally tend to wear out and run down. With each successive change, an isolated system loses potential—energy dissipates, concentrations disperse, gradients disappear. Eventually, the system reaches 'thermodynamic equilibrium', a state of maximum entropy in which no point is distinguishable from any other and nothing further can happen.

Of course, many systems in nature from new-born infants, through cities, to the entire ecosphere are hardly sliding toward equilibrium. The ecosphere, for example, is a highly-ordered self-organizing system of mind-boggling complexity, multi-layered structure and steep gradients represented by millions of distinct species, complex functional dynamics and accumulating biomass. Over geological time its internal diversity, structural/functional complexity, and energy/material flows have generally *increased*—i.e., the ecosphere has been moving ever *further* from the equilibrium state. Indeed, this phenomenon may well be the measure of life. As Prigogine (1997) asserts, "distance from equilibrium becomes an essential parameter in describing nature, much like temperature [is] in [standard] equilibrium thermodynamics".

Since living systems *gain* in structural mass and functional complexity over time, scientists and philosophers long thought they were exempt from the second law. This is not the case—all systems are subject to the same processes of entropic decay. (There are no known violations of the second law.) The paradox dissolves only when we recognize that all living systems, from cellular organelles to entire ecosystems and the ecosphere are *open* systems that freely exchange energy and matter with their host 'environments'.

Most critically, systems biologists have begun to emphasize that living systems, including the human enterprise, exist in overlapping nested hierarchies in which each component sub-system ('holon') is contained by the next level up and itself comprises a complex of linked sub-systems at lower levels. (Think of Russian 'nesting' dolls). This organizational form is the basis for 'SOHO' (self-organizing holarchic open) systems theory (see Kay and Regier 2002). Within the hierarchy, each sub-system (or holon) grows and maintains itself using energy and material (negentropy) extracted from its 'environment'—its host system—one level up. It processes this energy/matter internally to produce and maintain its own structure/function and exports the resultant degraded energy and material wastes (entropy) back into its host. In short, all living organisms produce and maintain their *local* organization as far-from-equilibrium-systems (i.e., they increase local negentropy) at the expense of increased *global* entropy, particularly the entropy of their immediate host systems (Schneider and Kay 1994, 1995). Because all self-organizing systems survive by continuously degrading and dissipating available energy and matter they are called 'dissipative structures' (Prigogine 1997).

SOHO thermodynamics should revolutionize economists' understanding of 'humans-in-nature'. Ecological economists argue that the entire human enterprise, like the ecosphere, is a self-organizing far-from-equilibrium dissipative structure. However, the human enterprise is also an open, growing, dependent *sub*-system of the materially closed, non-growing finite ecosphere (Table 1 and Fig. 2). Thus, while the ecosphere evolves and maintains itself in dynamic steady-state by 'feeding' on an extra-terrestrial source of energy and by continuously recycling matter, the human sub-system continuously grows by 'feeding' on its supportive ecosystems and injecting its wastes back into them. From this perspective, the most important flows in the economy are not the circular flows of money values but rather the one-way, irreversible flows of energy and material. In effect, the growing increasingly consumption-based human enterprise is thermodynamically positioned to consume and dissipate the ecosphere from the inside out (Rees 1999).[6]

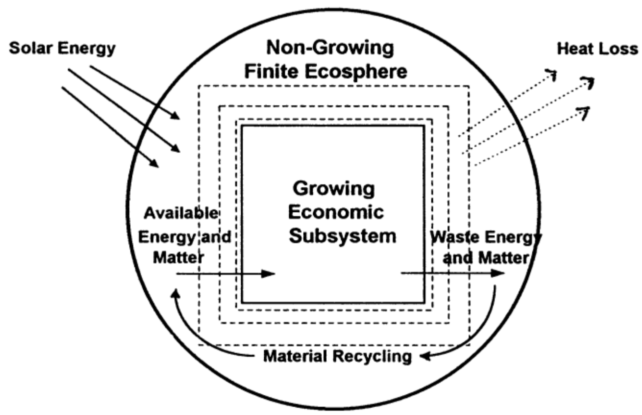

Figure 2: Ecological or steady-state or economics sees the human enterprise as an open, fully-contained dependent subsystem of the living but non-growing ecosphere.

Let's pause to ponder the socio-economic implications of this relationship.[7] Again, SOHO theory and far-from-equilibrium thermodynamics dictate that the human subsystem can grow and maintain its internal order

[6] Compare Figure 2 with Figure 1 and note how a simple change in structural relationships changes virtually everything else. In Fig 3, there is no separate 'environment' only the ecosphere and the latter *includes* the entire human enterprise. Instead of floating free from biophysical constraints, the economy is a fully contained by, and wholly dependent on, the ecosphere (see Daly 1991). As such, it is potentially parasitic on its host (Rees 1999).

[7] Renegade economist Nicholas Georgescu-Roegen (1971a, 1971b) was among the first to understand the implications of the second law for the human economy. Since all economic activity must draw low entropy resources out of nature and dump useless high entropy waste back in, he reasoned first that "…in a finite space there can be only a finite amount of low entropy and, second, that low entropy continuously and irrevocably dwindles away." He further speculated that since modern humans are unlikely to practice restraint in their use of resources, nature and human nature may combine to ensure that "…the destiny of man is to have a short but fiery, exciting, and extravagant life…" (Georgescu-Roegan 1975).

only by degrading the ecosphere and increasing global entropy. The production of *anything*—an e-mail message, our own bodies, an ocean liner—requires the extraction and dissipation of useful energy and material and the ejection of useless waste. These are irreversible processes. The energy consumed is almost immediately permanently radiated off the planet and, while the material may remain in the system, it is often chemically transformed and widely dispersed into the air soils and water. Recapturing such dissipated material is economically impossible. Even recycling or reusing consolidated wastes (such as aluminum cans and glass bottles) invariably requires the consumption/dissipation of additional energy. To reiterate, *any* so-called 'productive' activity that raises the human system ever further from equilibrium is actually mostly a consumptive process that simultaneously degrades the ecosphere.

All of which means that, contrary to popular belief, *there is an inevitable and unavoidable conflict between* ***continuous*** *material economic growth and the maintenance of ecosystems integrity*. Indeed, every so-called 'environmental problem' from fisheries collapses and deforestation (overexploitation) to marine dead zones and GHG accumulation (excess waste pollution) can be explained by reference to second law relationships. This in turn suggests two hard criteria for biophysical sustainability: The human enterprise must not on average consume more of 'nature's goods and services than ecosystems can produce nor discharge more wastes than ecosystems can assimilate or it risks descent into entropic chaos. And there is no escape from the grip of the second law. As physicist Sir Arthur famously observed:

> [Thermodynamics]…holds the supreme position among the laws of nature… If your theory is founded to be against the Second Law of Thermodynamics, I can give you no hope; there is nothing for it but to collapse in deepest humiliation (Eddington 1929).

The human ecological footprint

Consistent with the foregoing, the first questions of human ecology and sustainability economics should be: "How much of Earth's biocapacity is required to sustain any specified human population?" and "How does this compare with available supplies?" We can answer these questions using ecological footprint analysis (EFA) (Wackernagel and Rees 1996, Rees 2006, WWF 2008, 2010). As with other tools in ecological economics, the emphasis shifts to physical flows from money flows.

EFA starts from a series of inarguable premises:

- The human enterprise is an integral and fully dependent subsystem of the ecosphere;
- Most human impacts on ecosystems are associated with energy and material extraction and waste disposal (i.e., economic activities);
- We can convert many of these energy and material flows to a corresponding area of productive or assimilative ecosystems;
- There is a finite area of productive land and water ecosystems on Earth.

We therefore formally define the ecological footprint of any specified population as:

> The aggregate area of land and water ecosystems required on a continuous basis to produce the resources that the population consumes, and to assimilate (some of) the wastes that the population produces, wherever on Earth the relevant land/water may be located (Rees 2006).

Population eco-footprints are based on final demand for goods and services. The area of the eco-footprint therefore depends on four factors: the population size, its average material standard of living, the average productivity of land/water ecosystems, and the efficiency of resource harvesting, processing, and use. Regardless of the relative importance of these factors and how they interact, *every population has an ecological footprint* and the productive land and water captured by EFA represents much of the 'natural capital' (productive natural resource base) required to meet that study population's consumptive demands.[8]

Note also that ecological footprints can be interpreted in terms of thermodynamic theory. The human enterprise is a 'dissipative structure' whose metabolic activities irreversibly dissipate useful energy and material (negentropy) and increase global entropy. It follows that, since the production of renewable resources is driven by solar energy, a population's ecological footprint is the area required, on a continuous basis, to regenerate photosynthetically the energy and biomass equivalent of the negentropy being consumed by that population. This rate of consumption is theoretically sustainable as long as adequate exclusive productive ecosystem area (biocapacity) is available.

The comparative eco-footprints of nations

Because consumption depends on income, per capita eco-footprints are strongly correlated with GDP per capita. Figure 3 shows the average per capita eco-footprints for a cross-section of countries. The citizens of rich countries like the United States and Canada need an average of 4–10 global average hectares (gha) (10–25 acres) to support their consumer lifestyles. Meanwhile, the chronically impoverished get by on less than half a hectare (one acre) (WWF 2008).

Unlike abstract sustainability indicators that have no theoretical limits (e.g., GDP per capita), EFA can be used to compare demand with available supply. Significantly, the data show that many (mostly rich) countries have eco-footprints several times larger than the area of their domestic productive land- and waterscapes. The Netherlands, for example uses four times as much productive ecosystem area as is contained within its own borders; Japan's eco-footprint is *eight* times greater than the country's domestic biocapacity. Neither country could support more than a fraction of its present population on domestic biocapacity if cut off from external sources by climate change, energy shortages or geopolitical conflict.

Even if they have fiscal surpluses, all such countries are running ecological deficits with the rest of the world. This means that their populations survive mostly on biocapacity (both productive and assimilative capacity) appropriated from poorer countries, a few large relatively low-density countries such as Canada, and the global commons. Eco-footprinting thus reveals a hidden impact of global trade. The enormous purchasing power of the world's rich nations enables them to finance their ecological deficits by extending their

---

[8] EFA is not intended to represent all human impacts, only those material demands that can readily be converted to a corresponding ecosystem area. Toxic wastes, for which there is no assimilative capacity, are not represented; similarly, such impacts as stratospheric ozone depletion are excluded because they cannot be converted into ecosystem area. We also err on the side of caution whenever data are sparse or conflicting. For all these reasons, EFA generates a *conservative* estimate of total human load.

ecological footprints deeply into exporting nations and the open ecosphere. Wealthy and powerful nations can now achieve through global commerce what used to require territorial occupation. From the ecological economics perspective, globalization has enabled an increasingly unsustainable entanglement of nations in which the world's moneyed elites gain market access to remaining pockets of productive natural capital, often at the expense of the poor. This relationship is clearly not sustainable under conditions of continuous growth.

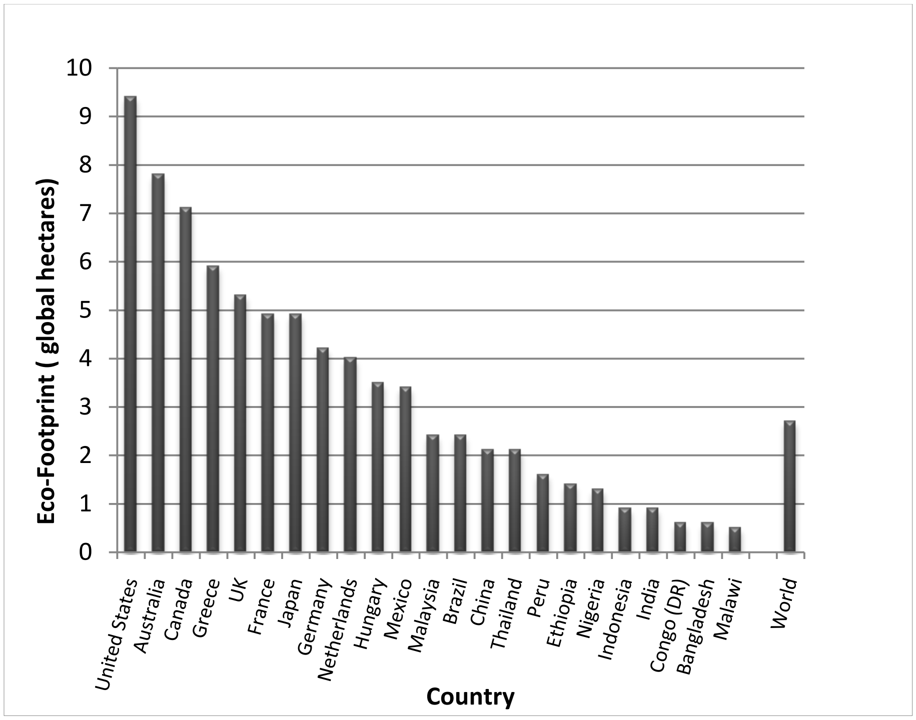

Figure 3: Per Capita Ecological Footprints of Selected Countries (2005 data from WWF 2008).

Eco-footprints and global equity

Globalization creates additional problems. By separating production from consumption, globalisation blinds consumers to the fact that their survival may depend on the sustainable management of land- and waterscapes half a world away. Meanwhile, competition among commodity suppliers bids down world market prices and dissipate producer surpluses some of which might have gone toward maintaining productive natural capital. Long-distance exploitation therefore tends to accelerate the depletion of the foreign ecosystems upon which the importing populations now depend and risks the long-term sustainability of *both* trading partners (Kissinger and Rees 2009).

Another obvious problem is that not all countries can run eco-deficits—for every sustainable deficit there must be a permanent surplus somewhere else. Unfortunately, the apparent 'surpluses' of the few large 'under-populated' countries such as Australia and Canada have already been absorbed into the eco-deficits of other countries. This means that there *is* no global eco-surplus. On the contrary, the average citizen of Earth had an eco-footprint of 2.7 gha (Fig. 3) while there are only ~1.8 ha of bio-productive land and water per person on the planet (WWF 2010). Although half the population is still in poverty, the world is well into a state of ecological 'overshoot'—the human enterprise is using about 50% more bio-productive and waste sink capacity annually than the ecosphere can regenerate. The world community is living, in part, by depleting natural capital and degrading ecosystems essential for survival—the very definition of unsustainability.[9]

Eco-footprint studies draw out another sobering socio-economic reality inaccessible to mainstream analysis. Extending the wealthy lifestyles of North Americans or Europe to the poor is wishful thinking. To raise just the present global population to North American material standards using existing technologies would require the biocapacity of 4-5 Earth-like planets. Since appropriate miracle technologies are not yet available, and we are unlikely to acquire the services of even one more Earth, we will probably have to do with the one we have. Perhaps we should get used to it!

Conclusions: Strong sustainability, equity and the steady-state economy

> "… a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (Planck, 1949, p.33)

Far-from-equilibrium thermodynamics and EFA underscore the fact that the human enterprise is fully imbedded in the ecosphere. Civilization remains dependent on natural capital and dematerialization is not taking place. Indeed, demand is increasing exponentially while supply is declining. These facts underscore the central place of the strong sustainability criterion in any global sustainability initiative:

> A society is sustainable if and only if it maintains adequate *per capita* physical stocks of productive natural capital (biocapacity) from one accounting period to the next. (Manufactured capital should similarly be maintained, but in a separate account).

The world is currently in violation of this criterion; the human enterprise is in overshoot. Consumption increasingly exceeds sustainable (Hicksian) natural income on the global scale so that capital stocks (and therefore subsequent sustainable income) are in decline.

Can we 'socially construct' an alternative economic model and economy that better maps to reality? First we must acknowledge that because it is a global in scale, unsustainability is a collective problem requiring collective solutions. No person nor nation can become sustainable on his/its own. Perhaps for the first time in human history, *individual and national self-interest has converged with humanity's collective interests* (Rees 2008).

In grasping this nettle, humanity has several qualities that set us apart, at least in degree, from other species: intelligence and reason; the capacity to plan ahead; and the ability to extend compassion to others. How should such qualities be expressed to ensure the mutual sustainability of global society? Reason obviously dictates that both national and global policies for sustainability be consistent with the scientific evidence. We must therefore plan to restructure the global economy so that aggregate economic activity operates in a

[9] The complementary empirical data include accumulating greenhouse gases, climate change, fisheries collapses, soil depletion, etc.,—all are symptoms of general overshoot.

dynamic ‘steady-state’ safely within the productive and assimilative limits of nature. To maintain adequate stocks of self-producing natural capital the world community should impose ‘best science’ quotas on harvests. Similarly, we should limit the exploitation of essential non-renewables and ensure investment of a sufficient portion of the proceeds in efficiency research or the search for alternatives. Once sustainable harvest and extraction rates have been set, auctions or other markets could be use to ensure the efficient allocation of available quotas among competing processors. Perverse subsidies that encourage over-exploitation and over-consumption must be phased out—market prices must reflect the true social costs of production.

Let’s also assume that as good global citizens we acknowledge that today’s levels of gross material disparity are intolerable. The richest 20% of the world’s population enjoy 76.6% of private consumption the poorest 20% subsist on 1.5%. Almost half the human family remain in poverty living in degraded environments without basic services on less than $2.50 per day (at purchasing power parity) (Shah 2010). Exercising their compassion for others, the wealthy should acknowledge that their historic levels of consumption are responsible for most ecological degradation to date and cannot be extended to the entire population. Basic equity considerations therefore require that rich countries initiate programs to *shrink* of their national economies toward a viable energy/ material steady-state. North Americans, for example, would have to reduce their ecological footprints by approximately 78%, from eight global average hectares (gha) *per capita* to an ‘equitable Earth-share’ of 1.8 gha (data from WWF 2010). Because humanity is already in overshoot, such contraction at the top is necessary to make room for needed growth in the developing world (Rees 2008, Victor 2008).

Giving up growth for sustainability-with-equity should actually not be difficult. Intelligent, well-informed citizens should be able to appreciate that in already rich countries further income growth produces no additional improvements in either population health or subjective well-being (Myers and Diener 1995, Lane 2000, Victor 2008).[10] Average incomes in such countries are sometimes three to five times higher than necessary for optimal returns—further material growth merely degrades the ‘environment’ and appropriates ecological space needed for justifiable growth in low-income countries.[11] Moreover, greater equity is itself better for everyone. Wilkinson and Pickett (2009) show that today’s widening income gap (more that poverty itself) is associated with declining population health and civil unrest and even heightens competitive consumption. Social stability and sustainability are associated with reduced income disparity. Logic therefore dictates that even powerful nations should plan for greater equity—compassion aside, it is in their own long-term self-interest to do so. There is even good news on the material side. Weizsäcker *et al*. (2009) show that

[10] For example, the Canadian economy has grown by 130% since 1976 and GDP per capita is 70% higher. Nevertheless, there has been no change in the percentage of people in poverty or unemployed and the absolute numbers of both have increased (Victor 2008). Meanwhile, subjective well-being is constant or declining.

[11] Daly argues that the world may already entered a stage of ‘uneconomic growth’ in which the unaccounted social and ecological costs exceed the tangible benefits. This is growth that, in the aggregate, makes us poorer rather than richer. Unfortunately, the poor and weak suffer the costs while the rich and powerful reap the benefits (and have little incentive to change under the current paradigm).

the world already has the technology to enable the required 75%-80% reduction in energy and (some) material consumption while improving quality of life in both rich and poor countries.

Finally, we should have no fear of life in a steady-state economy. 'Steady-state' simply implies that the 'throughput' of low entropy energy/matter reaches an optimum and then becomes more or less constant at the level required for maintenance and renewal. After an initial phase of growth, all healthy living systems including our own bodies, become steady-state systems. At the population and ecosystem levels, the innate propensity for further expansion constrained by negative feedback (e.g., incipient resource scarcity, predation, disease). Even the ecosphere as a whole is in approximate steady-state limited by the constant solar flux, the geographically variable availability of water and nutrients, and internal dynamics (including negative feedback). The economic sub-system has become the dominant subsystem of the ecosphere, and must increasingly conform to the operational dynamics of its host system if it is to survive. And the operational dynamics of its host are steady-state dynamics.

Note that a steady-state is not to be confused with a static state. The economy needn't cease developing, it must merely stop growing. With luck and sound management it could hover indefinitely in the vicinity of its 'optimal scale' while human well-being steadily improves. There are no limits on the capacity of human ingenuity to better our quality of life, only on the quantity of throughput available to do it. And even within that constraint, new firms and even whole industrial sectors could both develop *and* grow even as their thermodynamic equivalents in obsolete or 'sunset' industries are phased out.

Epilogue

There is, of course, almost no possibility that the global community will opt for anything like the sustainable steady-state-with-equity described above. It goes against the prevailing paradigmatic grain; instinct, emotion and habit regularly trump reason; society is in deep denial about the ecological crisis; humans rarely rise to their true potential in politics. According to historian Barbara Tuchman, sheer folly or "wooden-headedness" often plays the dominant role in government. "It consists in assessing a situation in terms of preconceived fixed notions [e.g., ideology] while ignoring any contrary signs. It is acting according to wish while not allowing oneself to be deflected by the facts" (Tuchman 1984, p.7).

In this light, the most plausible alternative to the steady-state strategy is entrenchment of the growth-bound, competitive, every-nation-for-itself *status quo* or some technologically engineered variant. But if our best science is correct, the increasingly likely outcome of such alternatives is ecosystemic collapse, resource wars and geopolitical chaos. Not what one might expect from a *truly* intelligent, forward-looking, compassionate species.

References

Berger P.L. and T. Luckmann. 1966. *The Social Construction of Reality*. Doubleday, Garden City, NY.

Christensen, Paul. 1991. Driving forces, increasing returns, and ecological sustainability. In R. Costanza, ed. *Ecological Economics: The Science and Management of Sustainability*. Columbia University Press, New York.

Coase, R. 1997. *Interview with Ronald Coase*. Inaugural Conference, International Society for New Institutional Economics. St. Louis, USA (September 17, 1997). Available at http://www.coase.org/coaseinterview.htm (Accessed 15 March 2011).

Daly, H. 1991. *Steady-State Economics* (2nd ed). Island Press, Washington.

Daly, H.E. 1999. *Uneconomic growth in theory and in fact*. The First Annual Feasta Lecture Trinity College, Dublin (26th April, 1999). Available at http://www.feasta.org/documents/feastareview/daly.htm (Accessed 10 March 2011).

Eddington, A.S. 1929. *The Nature of the Physical World*. Macmillan Company, New York ([re]Published by Kessinger Publishing, 2005).

Georgescu-Roegan, N. 1971a. *The Entropy Law and the Economic Problem*. Distinguished Lecture Series No 1. University of Alabama, Department of Economics

Georgescu-Roegan, N. 1971b. *The Entropy Law and the Economic Process*. Harvard University Press, Cambridge

Georgescu-Roegen, N. 1975. Energy and Economic Myths. *Southern Economic Journal*, Vol. 41, No. 3

Heilbroner, R. and L. Thurow. 1981. *The Economic Problem*. Prentice Hall, New York.

Kay J. and H. Regier. 2001. Uncertainty, complexity, and ecological integrity. In: Crabbé P, Holland A, Ryszkowski L, Westra L (eds) *Implementing Ecological Integrity: Restoring Regional and Global Environment and Human Health* (NATO Science Series IV: Earth and Environmental Sciences Vol 1, pp.121-156) Kluwer Academic Publishers, Dortrecht.

Kissinger, M. and W.E. Rees. 2009. Footprints on the Prairies: Degradation and Sustainability of Canadian Agricultural Land in a Globalizing world. *Ecological Economics* 68: 2309–2315.

Lane, R. 2000. *The Loss of Happiness in Market Democracies.* Yale University Press, New Haven.

Myers, D. and E. Diener. 1995. Who is Happy? *Psychological Science* 6, no. 1: 10-19.

Nikiforuk, A. 2006. 'At war with our planet,' review of *The Weather Makers: How We Are Changing the Climate and What it Means for Life on Earth* by Tim Flannery (Harper Collins, 2006). *The Globe and Mail* (Section D), Toronto (4 March, 2006.)

Planck, M.K. 1949. *Scientific Autobiography and Other Papers*. Philosophical Library, New York.

Popper, K. 1972. Conjectural Knowledge: My Solution of the Problem of Induction. In Karl Popper, *Objective Knowledge: An Evolutionary Approach*. Oxford University Press, Oxford.

Postman, Neil. 1999. *Building a Bridge to the 18th Century*. Alfred Knopf, New York.

Prigogine, I. 1997. *The End of Certainty: Time, Chaos and the New Laws of Nature*. The Free Press, New York.

Randall, A. 1988. What Mainstream Economists Have to Say about the Value of Biodiversity. Chapter 25 (pp 217-223) in E.O, Wilson, ed. *Biodiversity*. National Academy Press, Washington DC.

Rees, W.E. 1999. Consuming the Earth: The Biophysics of Sustainability. *Ecological Economics* 29: 23-27.

Rees, W.E. 2006. Ecological footprints and bio-capacity: essential elements in sustainability assessment. Chapter 9 in: J. Dewulf and H. Van Langenhove, eds. *Renewables-based Technology: Sustainability* Assessment. Wiley, Chichester, UK.

Rees, W.E. 2008. Human nature, eco-footprints and environmental injustice. *Local Environment* 13(8): 685 – 701.

Rees, W.E. 2010. What's blocking sustainability: Human nature, cognition and denial. *Sustainability: Science, Practice and Policy* (6): 2. Available at: http://sspp.proquest.com/archives/vol6iss2/1001-012.rees.html

Rockström, J. *et al.* 2009. A safe operating space for humanity. *Nature* 461: 472-475.

Schneider E.D and J.J. Kay. 1994. Complexity and Thermodynamics: Toward a New Ecology. *Futures* 26: 626-647.

Schneider E.D and J.J. Kay. 1995. Order from Disorder: The Thermodynamics of Complexity in Biology. In: Murphy MP, O'Neill LAJ (eds) *What is Life: The Next Fifty Years*. Cambridge University Press, Cambridge, U.K.

Shah, A. 2010. (updated 20 Sept 2010). Available at: http://www.globalissues.org/article/26/poverty-facts-and-stats (Accessed 13 Mar 2011)

Solow, Robert. 1974. The Economics of Resources or the Resources of Economics. *American Economics Review* 64(2): 1-14.

Victor, P. 2008. *Managing Without Growth*. Edward Elgar, Cheltenham.

von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. 2009. *Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity*, Earthscan, London, UK and Droemer, Germany.

Wackernagel, M. and W. Rees. 1995. *Our Ecological Footprint*. New Society Publishers, Gabriola Isld, BC.

Wackernagel, M. and W. Rees. 1995. Our Ecological Footprint. New Society Publishers, Gabriola Isld, BC.

Wilkinson, R. and K. Pickett. 2009. *The Spirit Level: Why Equality is Better for Everyone.* Penguin Books, London.

Wolf, M. 2010. *Why were resources expunged from economics?* Wolfexchange. London: Financial Times. Available on line, at: http://blogs.ft.com/martin-wolf-exchange/2010/07/12/why-were-resources-expunged-from-neo-classical-economics/ . (Accessed 15 Mar 2011).

WWF. 2008. *Living Planet Report 2008*. World Wide Fund for Nature, Gland, Switzerland.

WWF. 2010. Living Planet Report 2010. World Wide Fund for Nature, Gland, Switzerland.

Table 1: Comparing Competing Economic Paradigms[12]

Property or Quality	*Neoliberal (Expansionist) Worldview*	*Ecological Economics (Steady-State) Worldview*
Epistemological and scientific origins	Modern roots in the enlightenment and accompanying scientific revolution (Copernicus, Galileo, Bacon, Décartes, Newton) of 16th to 18th Centuries; Newtonian analytic mechanics.	Derived from 20th Century physics and biology; Prigoginian self-organization (dissipative structures), far-from-equilibrium thermodynamics, complex systems theory, deterministic chaos, and systems ecology.
Central scientific premise	Nature is knowable through reductionist analysis, observation and experimentation; the observer is separate from the observed; nature is thus objectified (the origin of "objective" knowledge).	The behaviour of natural systems is unknowable (unpredictable) at the whole systems level,[13] uncertainty is large and irreducible within wide margins; holistic approaches provide the best understanding of global change but whatever our investigative stance, humankind is an integral part of the ecosphere; there is no truly objective knowledge.
Structure of analytic and managemnet models	Foundational models tend to be simple, linear, deterministic, and single equilibrium-oriented; management strategies assume smooth change, complete reversibility and little risk.	Models are complex, non-linear, dynamic, and characterized by multiple equilibria; management strategies recognize abrupt discontinuities, dynamic boundary conditions, and potential irreversibilities, necessitating a cautious (risk-averse), boundary-oriented approach.
Attitude toward people and the future	Emphasis on the individual and immediate national interests; primary concern for the present generation; comfortable with time and space discounting.	Greater emphasis on community and collective interests generally; concerned about present and future generations; cautious about conventional discounting.
Perspectives on Nature	Humankind is the master of nature; people can adapt "the environment" at will to serve their wants and needs; values nature mainly as a source of resources and sink for wastes.	Humanity lives in a state of obligate dependence on the ecosphere; resources ultimately control people; there are few examples of industrial "man" successfully managing or controlling resource systems sustainably (e.g., fisheries, forests, agricultural soils). In addition to production value and exchange value, 'nature' has intrinsic worth, value for its own sake.
Economic paradigm and connectedness to ecosphere	Neoliberal (neoclassical) economics treats the economy as an growing, independent system; analytic models are generally inorganic and mechanical, lacking any physical representation of the material and energy transformations and the structural and time-dependent processes of complex systems (see Christensen 1991).[14]	Ecological economics sees the human economy as a fully contained, dependent, integral sub-system of the ecosphere; industrial metabolism should be analyzed as a thermodynamic extension of human metabolism. Understanding the physical/material transformations that bind the economy and ecosystems, maintaining essential ecosystems functions, and recognizing the lags and thresholds characterizing ecosystems and socioeconomic systems behaviour is paramount to sustainability.
Starting point for analysis	The circular flows of exchange value between firms and households (with money as the metric).	The unidirectional and irreversible flows of low-entropy energy/matter from nature through the economy and back in degraded form.[15] (Physical measures of stocks and flows should at least supplement money as the metric.)
Role and ecological efficacy of markets	Free markets stimulate (through rising scarcity value and corresponding prices) both the conservation of depleteable assets and the search for technological substitutes; free markets and technology can therefore help decouple the economy from nature.	Markets 'work' for a limited range of familiar non-renewable resource commodities but prices for renewable flows are inadequate indicators of ecological scarcity. Market prices reveal only exchange value at the margin and do not reflect the size of remaining natural capital stocks, 'transparent' ecological functions, whether there are critical minimal levels below which stocks cannot recover, nor the ultimate contribution of such stocks to human existence or survival. There are no markets for many biophysical goods (e.g., the ozone layer) and essential life-support services (e.g., photosynthesis and waste assimilation) which have immeasurable positive economic value. Material decoupling is not occurring and is impossible.
On the substitutability of natural capital	Natural capital and manufactured capital are near-perfect substitutes. Human ingenuity and technology can make up for any depleting natural resource. (Typical quote of proponents: "Exhaustible resources do not pose a fundamental problem" [Dasgupta and Heal 1979, 205]).[16]	Natural capital is complementary to and often prerequisite for human-made capital. Given the market failures noted above, the standard measures of scarcity (prices and costs) may fail absolutely to induce either the conservation of vital stocks or technological innovation. In any case, it is unlikely humans will devise technological substitutes for many ecospheric life support functions whose loss would be irreversible and potentially catastrophic.

12. Adapted from Rees (1995). Achieving sustainability: Reform or transformation. *Journal of Planning Literature* 9 (4): 343-361.
13. Includes social and economic systems, i.e., any complex self-organizing system.
14. Christensen, P. 1991. Driving forces, increasing returns, and ecological sustainability. In *Ecological Economics: The Science and Management of Sustainability* (R. Costanza, ed.). New York: Columbia University Press.
15. Even 100% material recycling of the original good would consume additional net energy and ordered matter.
16. P. Dasgupta and D. Heal. 1979. *Economic Theory and Exhaustible Resources*. Cambridge: Cambridge University Press.

Table 1: Comparing Competing Economic Paradigms (continued)

Attitude toward economic growth **a) social role of growth**	Economic growth is strongly associated with human well-being. Growth in both rich and poor countries is essential as the only practical means available to alleviate human poverty within nations and to address material inequities between countries.	Beyond a measurable point, long past in most rich countries, neither objective nor subjective indicators of population health and individual well-being increase further with income growth. Any available ecological space for growth should therefore be allocated to the Third World. Perversely, growth under prevailing economic dynamics mainly accrues to the already rich (who don't need it) and cannot be relied upon as the means to relieve material poverty. Equity requires significant intra- and international redistribution of wealth and access to nature's services. Political, social, economic and institutional reforms are needed to facilitate the necessary behavioral, value and attitudinal changes. This in turn calls for sophisticated public education programs on sustainability issues.
b) ecological role of growth	Growth in the developed world will increase the market for the products of developing countries. This will enrich developing countries, helping to provide the surpluses needed for the rehabilitation and future sustainable use of natural capital. (This paradigm often sees depletion of natural capital and local pollution as a Third World problem.)	We cannot safely grow our way to sustainability, particularly in the First World—the global economy is already running a large hidden ecological deficit, attributable mostly to consumption in rich countries. Far from providing the surpluses needed to rehabilitate natural capital, material growth based on current economic assumptions and available technology depends on its further depletion, increasing the sustainability deficit and leading to accelerated ecological decline. Real wealth is measured by supportive social relationships, enduring cultural artifacts, dynamic sociopolitical institutions, growing natural capital stocks, and long-term ecological security.
c) Nature of limits	There are practical limits on human population, but no constraints on economic growth (i.e., on *per capita* GDP); technology can generally substitute for depleted natural capital and, over time, the economy can be "dematerialized" by increases in economic and technological efficiency.	There are real biophysical constraints on both population and material throughput growth; humankind must live on the natural income generated by remaining stocks of natural capital. Total human impact or load is the product of population and average per capita material consumption (including waste output) and cannot be reduced below critical maximum safe levels in the foreseeable future by technology and efficiency gains alone. Ecological fiscal reform is necessary to ensure 'prices tell the truth.'
Stance on carrying capacity[17]	There are no significant limits to regional or global carrying capacity; trade can relieve any locally significant limiting factors and technological advances will alleviate more general scarcities (see above).	Carrying capacity is finite and declining and should become a fundamental component of demographic and planning analysis. Trade and technology appear to increase local carrying capacity, while actually accelerating the depletion of vital natural capital stocks on a global scale. With unregulated trade, all trading regions can exceed domestic territorial capacities, become dependent on imports of depleteable resources, and ultimately bump up against the same globally limiting factor(s). (At this stage, there are no further safety valves.)
On GDP as welfare indicator	GDP (or per capita GDP) is an imperfect indicator, but correlates well with standard measures of population health and remains the best overall measure we have of human welfare.	GDP is woefully inadequate as a measure of social and ecological welfare. It says nothing about the distribution of the benefits of growth—average *per capita* GDP can rise while the money income of poorer people falls in real terms. In high income countries, the relationship between rising incomes and subjective well-being may actually become *negative*. In any case, GDP typically includes the depreciation of manufactured capital, environmental health costs, and defensive expenditures against pollution and other forms of ecological decline as positive entries, and does not account for the depletion of natural capital. GDP can therefore continue to increase, creating the illusion of increasing well-being, while economic, ecological, and geopolitical security are all being eroded (This describes Herman Daly's "'anti-economic growth'— i..e., growth that makes us poorer rather than richer" [Daly 1990/1, 242])[18]
Attitude toward globalization	Deregulation, global markets, and free trade enhance economic efficiency and contribute to greater social equity and international security through expansive growth in world product (GWP).	Deregulation, expanding markets, and free trade will indeed increase gross global product, but under prevailing assumptions and terms of trade they also increase income disparities and accelerate the depletion of natural capital thereby decreasing both ecological and geopolitical security. Intervention in markets (e.g., depletion and pollution charges, ecological fiscal reform) will be necessary for sustainability.

17. Carrying capacity is usually defined as the maximum sustainable population in a given area, but is better thought of as the maximum sustainable human "load" (population × resource consumption/capita) (see William Catton. 1986. Carrying capacity and the limits to freedom. Paper prepared for Social Ecology Session 1, XI World congress of Sociology. New Delhi, India [18 August, 1986]). This is the basis for ecological footprint analysis.

18. Daly, Herman E. 1990. Sustainable development: from concept and theory towards operational principles. Population and Development Review (special issue) (Reprinted in: Herman E. Daly. 1991. Steady State Economics (2nd ed.). Washington: Island Press.