Chapter 2

Integrated sustainability and the underlying threat of urbanization

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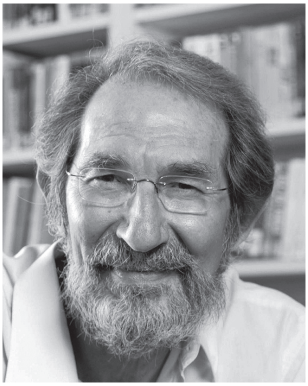

Geoffrey B. West, born in England in 1940, received his BA from Cambridge University in mathematics and physics in 1961, and his doctorate from Stanford University in 1966. He later joined the Stanford faculty in 1970. His primary interests have been in elementary particles, their interactions and cosmological implications. He was the founder of the high-energy physics group at Los Alamos National Laboratory. In 2003 West joined the Santa Fe Institute as a distinguished professor and was named its president in 2005. His interest in universal scaling laws led him to develop quantitative models of organisms based on universal principles. Recently he extended these ideas to studying quantitatively the structure and dynamics of cities and corporations, including the relationships between efficiency, growth, innovation and sustainability. He has received numerous awards and was included in Time Magazine's 2006 list of the 100 most influential people in the world.

Note: This chapter is a commentary on chapter 1.

In this essay I want to emphasize two major themes that have not received the attention I believe they deserve if we are to seriously tackle the question of long-term global sustainability in its broadest sense. In so doing I take for granted that it is important and fundamental to formulate the questions, problems and solutions relating to sustainability within a scientific paradigm. Such a paradigm can provide a credible platform for the socio-political leadership inevitably needed to effect change. An underlying motif will be a rallying call to recognize the importance of breaking down the boundaries between traditional academic disciplines. This includes the equally pressing question, not addressed here, of the inter-relationship between science, culture and politics – the 'three cultures problem'.[1] In this respect some of what I have to say builds on remarks made by my colleague Murray Gell-Mann, who emphasized transdisciplinarity, and encouraged the development of coarse-grained descriptions of complex systems. The two major themes I will address here are:

1. The need for a broad, integrated scientific framework that encompasses a quantitative, predictive, mechanistic theory for understanding the relationship between human engineered systems, both social and physical, and the 'natural' environment. Somewhat whimsically, I shall refer to this conceptual framework as the *grand unified theory of sustainability.*
2. As a corollary to this, the recognition that cities and the ever-expanding urbanization of the planet have played a seminal underlying role in bringing us to this critical point in the planet's history. Intimately related to this are questions of the dynamics of innovation, cycles of boom and bust, the seemingly inevitable increase in the pace of life, and the spectre of a planet of slums, pollution, disease, and conflict.

In recent years increasing worldwide attention has been paid to a multitude of threatening phenomena, such as global climate change and the incipient crises in food, energy and water availability. The recognition of an impending crisis has led to burgeoning national and international concern about questions of global sustainability, and has stimulated a proliferation of programmes focused on many of these issues. These have been promoted not only by leading governmental and international organizations but also by corporate and other non-governmental institutions.

However, most of these programmes and almost all existing approaches to the challenge of global sustainability have focused on relatively specific issues, such

[1] This is a take on the title of the lectures given by C. P. Snow in 1959 highlighting the divide between the sciences and the humanities (Snow, 1993). Interestingly, Snow himself embraced all three cultures; he was a scientist, a well-known author, and very much involved in politics and high-level governmental decisions in an advisory capacity.

as the environmental consequences of future energy sources, the economic consequences of climate change, and the social impact of future energy and environmental choices. While such focused studies are of obvious importance and, indeed, are where most of our research efforts should be directed, they are not sufficient. No overarching, integrated conceptual framework has yet been developed that can provide a long-term big picture uniting the many highly inter-related themes underlying sustainability. Existing approaches have, to a large degree, failed to come to grips with the essence of the long-term sustainability challenge; namely, *the pervasive interconnectedness and interdependency of energy, resources, environmental, ecological, economic, social, and political systems.* Early attempts along these lines include the well-known Club of Rome report in 1972 (Meadows *et al.,* 1972) and, more recently, the Stern report to the UK government in 2007 (Stern, 2007). However, there has not yet been any attempt to develop an explicit, overarching, systematic, conceptual scientific framework. Without such an integrated 'bigger picture', we risk repeating the classic mistake of developing short-term, highly-focused 'solutions' tailored to a narrow sector of the totality, ignoring the tight relationships between issues, and their dependence on a myriad of other problems. This approach inevitably leads to long-term and potentially disastrous consequences. A well-known, small-scale example currently under discussion is the advocacy of biofuels. This has generally ignored the potential consequences of vastly increased biomass production for water demand, biodiversity, or the increased cost and reduced availability of food for human consumption, and its effects on markets (see, for example, Inderwildi and King (2009); Creutzig and Kammen, this volume). For a comprehensive approach to sustainability, we need to overcome such 'stovepiping' and provide an integrated holistic framework that addresses the pervasive interdependencies and interconnectedness of different systems.

A grand unified theory of sustainability?

It is becoming increasingly clear that one of the most profound challenges facing science and society today is the need for an *integrated* conceptual framework for understanding *sustainability* in its broadest sense. Such a framework is essential if we are to gain a comprehensive understanding of the multitude of strongly interacting factors that fall under the umbrella of sustainability, and which are typically treated as effectively independent. These include the following: (a) energy, food and resource production and consumption; (b) ecology, the environment, and climate change; (c) human population, health, and well-being; (d) the global economy, including the nature of risk and the dynamics of financial markets; and (e) the social, cultural, and political institutions and organizational structures upon which the preceding depend. Such a comprehensive understanding of the interacting and interdependent systems is critical if humankind is to make informed choices between the many competing 'solutions' to the energy, environment, economic, and social problems that constitute the sustainability challenge.

A priori, it is not at all clear whether such a lofty goal is indeed achievable. The extent of the problem is daunting and, until recently, very little attention had been given to thinking in these terms. Only now are tools and techniques being developed to address such questions, and it is far from apparent that anything like a serious quantifiable *unified theory of sustainability* is at all possible. Nevertheless, I would like to take a provocative position and suggest that such an exercise is worthwhile even if it fails, since it may, in any case, stimulate potentially new systemic ways of thinking, or even lead to an alternative, complementary paradigm. Perhaps most importantly, it may, at the very least, stimulate new questions, new areas of investigation or innovative ways of thinking that would otherwise not be quite so apparent when viewed only from a more restricted, highly focused perspective.

The concept of complex adaptive systems provides a potential framework for developing such an integrated, systemic, conceptual approach[2]. The ideas inherent in 'complexity science' have been developing slowly over the past 20 years and are now generally viewed as an exciting new paradigm for addressing the kinds of problems posed by the challenge of sustainability. Furthermore, the culture of complexity science has stimulated the emergence of a serious transdisciplinary approach, which is clearly required to address many of the key issues. The exploration of complex systems stemmed to a large degree from the realization that many mysteries of nature involve nonlinear behaviour. In these systems multiple feedback mechanisms play a major role, and the whole is substantially greater than, and often significantly different from, the sum of its parts. Many systems are composed of myriad relatively simple individual components. Yet, once aggregated they take on collective characteristics that are not manifested in, nor could be easily predicted based on, the components themselves. Such 'emergent phenomena' are typical of all social systems and characterize the kinds of interactions and problems associated with economies, markets, urban communities, the environment, the weather, the health system, and other complex systems. The study of complex systems has taught us to be wary of naively deconstructing the system into independently acting component parts, and that a small perturbation in one part of the system may have major unforeseen consequences elsewhere. This familiar phenomenon was spectacularly manifested last year by the meltdown of financial markets across the globe, apparently stimulated by misconceived dynamics in the relatively localized US mortgage industry, with potentially devastating social and commercial consequences worldwide.

[2] A good modern overview is provided by Mitchell (2008). See also Waldrop (1993).

The developing science of complexity embraces an integrated systemic approach that brings together a broad spectrum of powerful techniques and concepts. These include agent-based modelling, cellular automata, network theory, multi-scale thinking (both temporal and spatial), field theory, statistical physics, scaling theory, and the renormalization group. Furthermore, it addresses transdisciplinary questions and concepts that are central to any discussion of sustainability. These include adaptability, evolvability, robustness, resilience, regulation, and conflict. In addition, an important lesson learned in investigating many complex phenomena is that, while it is not typically possible to predict detailed aspects of the system, it is sometimes possible to derive a 'coarse-grained' description that allows for quantitative predictions of the generic, salient features of the system. The development of such a quantitatively predictive, coarse-grained theoretical framework encompassing the challenges of risk, financial markets, climate, the environment, health, pollution, urbanization, etc. would be a major accomplishment. It would allow not only an assessment of long-term questions of sustainability but would also provide the basis for cost-benefit analyses of alternative scenarios involving all of these highly-coupled phenomena.

As funding agencies and universities worldwide are beginning to recognize, complexity science coupled with a transdisciplinary approach will play an increasingly important role in the academic landscape of the twenty-first century. To quote Stephen Hawking[3]: 'Q: Some say that while the twentieth century was the century of physics, we are now entering the century of biology. What do you think of this? A: I think the next century will be the century of complexity.' What has yet to be appreciated, however, is that bringing such a perspective to the challenge of global sustainability and the long-term survival of our planet will be critical because it inherently recognizes the kinds of interconnectedness and interdependencies so frequently ignored in current discourse.

As an example, we need to develop a natural framework for understanding the fundamental and critical problem of how human social dynamics (manifested by the dominance of urban living – the source of and solution to most of our problems) drives the changing environment (usually in a negative way), as well as the reverse interaction of how the changing environment influences engineered and evolving human systems. A major challenge of the twenty-first century is the fundamental question as to whether human-engineered social systems, from economies to cities, which have only evolved over the past 5000 years, can coexist with the 'natural' biological world, which evolved over billions of years. We will only have a sustainable planet that can support over 10 billion people living in 'harmony' with

[3] Stephen Hawking quoted in an interview on January 23, 2000 in the San Jose Mercury News; see http://www.mercurycenter.com/resources/search.

the biosphere from which we evolved if we understand the principles and underlying dynamics of this social-environmental coupling.

The increasing worldwide attention paid to issues of sustainability is both gratifying and frightening; gratifying because it is one of the most critical issues facing humankind, and frightening because we risk the possibility of squandering huge financial investments and enormous social capital if we continue to pursue limited and single-system approaches to sustainability without developing a unifying framework. Now is the time to recognize that a broad, multi-disciplinary, multi-institutional initiative, guided by a broader, more integrated and unified perspective, is likely to play an important role in yielding sound scientific conclusions. A strong case can be made that now is the time to initiate a dedicated Manhattan-style project or Apollo-style programme for global sustainability in the integrated, systemic sense described here.

The central role of cities and urbanization: can we avoid a planet of slums?

In this last section I would like to present an example of how the broad perspective implicit in 'complexity science' can be usefully applied to a key issue in global sustainability, namely urbanization and the role of cities. This will be a highly condensed overview of a large body of work, some of which is well established but parts of which are perhaps a little more speculative. Though justice cannot be done in just a few paragraphs, this illustrates a way of thinking inspired by ideas falling under the rubric of complexity.

The future of humanity and the long-term sustainability of the planet are inextricably linked to the fate of our cities. It is estimated that in 2005 an historic threshold was crossed with more than half of the world's population now living in urban centres (UN, 2005). This is in marked contrast to the situation that pertained for almost the entire time-span of human existence over the last several thousand years, when almost all human beings resided in non-urban environments. For example, even as recently as the birth of the United States at the end of the eighteenth century, only a small percentage of Americans were urban dwellers, whereas today more than 80% live in cities. By 2050, this will very likely be true for the entire planet. The extraordinary growth of cities is often associated with the rapid rise of standards of living, prosperity and quality of life. Indeed, the more urbanized countries are, on average, richer. Moreover, the world's two most populous countries – China and India – are undergoing unprecedented experiments in rapid urbanization, with unforeseeable consequences for their future resource consumption, their impact on the natural environment, and social stability.

Cities have traditionally been, and continue to be, the sources of creativity, innovation and wealth production. They are hubs of social activity, the magnets that attract creative individuals, vacuum cleaners that suck up innovation, and stimulants for ideas, growth and wealth production. Analyses of data confirm this (Bettencourt *et al.,* 2007); regardless of which indicator one looks at, the larger the city the more innovative 'social capital' is produced. For example, if a city doubles in size, then, on average, wages, wealth, the number of patents and number of educational and research institutions all increase by approximately 15% on a per-capita basis. We refer to this systematic phenomenon as 'superlinear scaling'; the larger the city, the more the average individual resident owns, produces and consumes, whether it be goods, resources or ideas. As urban creatures we all participate in the multiple networks of intense human interaction manifested in the metropolitan buzz of productivity, speed, and ingenuity. This is the good news about cities and why they have been so attractive and seductive.

Now to the bad news: similar analyses of data representing the negative side of urban life manifest an analogous 'superlinear' behaviour. By approximately the same degree as for the positive indicators, negative indicators of human social behaviour also systematically increase with city size: doubling the size of a city not only increases wages, wealth and innovation by approximately 15% but also increases the amount of crime, pollution and disease to the same degree (on a per-capita basis). Apparently, the good, the bad and the ugly seem to come hand in glove as an integrated, almost predictable, package. A person may move to a bigger city drawn by more innovation, a greater sense of 'action' and better wages, but they can also expect to confront an equivalent increase in garbage, theft, stomach flu, and AIDS.

Until the middle of the last century, this dual nature of cities as the origin of wealth and ideas and, at the same time, the source of pollution and disease was not perceived as a serious threat because cities were still sub-dominant in terms of population. As cities began to dominate, their entropy production inevitably led to degradation of the environment, non-linear consequences for the climate, severe stresses on resources and energy, and the beginnings of the multiple problems we face under the banner of sustainability as we enter the twenty-first century. *Cities have emerged as the source of the biggest challenges the planet has faced since humans became social, yet cities are also the source of the solution since they are the reservoir of creativity and ideas.*

This remarkable and seemingly inextricable link between the benefits and costs of community structure very likely has its origins in the 'universal' dynamic of the network structure and group clustering of human interactions; when humans began serious interpersonal interactions about 10 000 years ago, forming sizeable communities, discovering economies of scale and the fruits of wealth creation, they brought a fundamentally new dynamic to the planet, a dynamic that went beyond biology. The resource and energy networks that have evolved in the 'natural world' to sustain biological organisms and ecosystems are primarily dominated by economies of scale ('sublinear scaling') – roughly speaking, the larger the organism, the less energy is required per second to support each one of its cells (West *et al.,* 1997; West and Brown, 2005). The dynamics of such networks constrain the pace of biological life to decrease systematically with increasing size. For example, large mammals live longer, take longer to mature, have slower heart rates, and cells that work less hard than those of small mammals, all to the same degree; (doubling the mass of a mammal increases time-scales, such as its lifespan and time to maturity, by about 20 % on average and, concomitantly, decreases all rates, such as its heart-rate, by the same amount). Small creatures live life in the fast lane while large ones move ponderously, though more efficiently, through life (think of a mouse versus an elephant!). The social networks that underlie the 'superlinear scaling' of wealth creation, innovation, crime and pollution behave in exactly the opposite fashion to these biological networks; the larger the organization, the faster the pace of life (Bettencourt *et al.,* 2007). In large cities, disease spreads more quickly, business is transacted more rapidly and people walk faster, all approximately to the same degree and in approximately the same systematic, predictable fashion (as a rule by approximately 15 %).

In biology a further consequence of economies of scale and of sublinear scaling is that organisms like mammals eventually stop growing, reaching some approximately fixed size at maturity (West *et al.,* 2001). Over time-scales that are very long compared to human social time-scales, biological systems are relatively stable and sustainable, with major changes taking place over many thousands to many millions of years. On the other hand, in social organizations where growth is driven by the superlinear scaling associated with wealth creation and social innovation, growth is unbounded, never reaching an 'asymptotic' stable state, and proceeding at a rate that is faster than exponential (Bettencourt *et al.,* 2007). To sustain such growth in light of resource limitation requires continuous cycles of paradigm-shifting innovations such as those associated in human history with the discovery of iron, steam, coal, computation, and, most recently, digital information technology. Indeed, the litany of such discoveries is testament to the extraordinary ingenuity of the human social mind in overcoming the looming threat of running out of the perceived essential resource. However, there is a serious catch: theory dictates that, to sustain continuous growth – one of the primary assumptions upon which modern societies have evolved – *such discoveries must occur at an increasingly accelerated pace; the time between successive innovations must inevitably get shorter and shorter. So, if we insist on continuous growth driven by wealth creation, not only does the pace of life inevitably quicken, but we must innovate at a faster and faster rate!*

Until recently the period of time between major innovations far exceeded the productive life span of a human being. Beginning towards the end of the twentieth century this was no longer true; a typical human now lives significantly longer than the period between major innovations. The period between the most recent major shift from the 'Computer Age' to the 'Information and Digital Age' was only about 20 years, which is to be compared with the order of thousands of years between the Stone, Bronze and Iron Ages. Furthermore, the time differential to the next significant innovation is destined to be even shorter. This is surely not sustainable, and, if nothing changes, we are heading for a major crash and a potential collapse of the entire socio-economic fabric. The challenges are clear: Can we return to an analogue of the 'biological' phase whence we evolved and be satisfied with 'sublinear scaling' and its attendant natural limiting, or no-growth, asymptotically stable configuration? Is this even possible? Can we have the kind of vibrant, innovative, creative society driven by ideas and wealth creation as manifested by the best of our world's cities and social organizations, or are we destined to a planet of urban slums and the ultimate spectre of devastation raised by Cormac McCarthy's novel The Road (McCarthy, 2007)?

Given the special, unique role of cities as the originators of many of our present problems and their continuing role as the super-exponential driver towards potential disaster, understanding their dynamics, growth and evolution in a scientifically predictable, quantitative framework is crucial to achieving long-term sustainability on the planet. Perhaps of even greater importance for the immediate future is to develop such a theory within the context of a 'grand unified theory of sustainability' by bringing together the multiple studies, simulations, databases, models, theories and speculations concerning global warming, the environment, financial markets, risk, economies, health care, social conflict and the myriad other characteristics of man as a social being interacting with his environment.

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