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Why Large Cities Won't Survive the Twenty-First Century

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Introduction: Setting the Scene

The population of the world's largest city, metropolitan Tokyo was near its all-time peak at 37.3 million people in 2021. This is roughly equivalent to the population of Canada, geographically the second largest country on Earth. This is truly an extraordinary population for a single city, but analysts expect it will soon be surpassed by several mega-cities in the developing world; by 2050, the largest megalopolis will be Mumbai at 42.4 million; by 2100 Lagos will take the population prize at 88.3 million – and 9 other developing country mega-cities are projected to top 50 million people by century's end (Hoornweg and Pope 2016).

Urbanization generally is accelerating. Half the world's people have been living in cities and towns since 2007; by 2018, over 4.1 billion people or 55% of the total population were urbanized and the UN projects this proportion to rise to 68% by 2050. Rural-urban migration combined with general population growth could add another

~2.5 billion people to the world's cities by 2050 (an increase of 61%). Ninety percent of this increase will take place in developing Asian and African cities (UN 2018) as the world population soars to 9.7 billion in 2050 on its way to perhaps 11 billion in 2100 (UN 2019).

Or maybe not.

Population projections are typically made by manipulating purely demographic data – present population, age distribution, age-specific fertility and mortality rates, net migration – *as if there were no "environment*." This approach can succeed only when nothing happens to affect key demographic variables. For example, during the past half century of continuous growth and increasing economic prosperity in much of the world, UN population forecasts have been fairly accurate and improving with increasing data reliability.

But coming decades will look nothing like the recent past. The human enterprise is now in a state of advanced ecological overshoot (Rees 2020). Eco-overshoot (hereafter, "EO") exists when the consumption of bioresources and the production of wastes exceed the regenerative and assimilative capacities respectively, of supportive ecosystems. When in EO, we can achieve further growth only by depleting essential natural capital and overtaxing the life-support functions of the ecosphere including the climate system, i.e., by destroying the biophysical basis of our own existence.

And that is precisely what we are doing. The global footprint network monitors the annual occurrence of "Earth Overshoot Day," the date in the year when humanity's demand for ecological resources exceeds nature's budget (supply) for that year (GFN 2021a). Each year, Overshoot Day occurs a little earlier as demand increases and eco-production declines with accelerating ecosystems degradation – in 2021, it fell on July 29. Remember, the difference between demand and supply can be made up *only* by depleting remaining natural capital stocks – fish stocks, forests, soil organic matter and nutrients, ground water, etc. – that took thousands of years to accumulate in nature, and by over-filling nature's waste sinks. (Even climate change is a waste-management issue – CO_2 is the greatest waste by weight of industrial economies.)

EO means that humanity is running an ecological deficit, an energy and material deficit far more important that the fiscal deficits that preoccupy politicians. Yet most politicians, like their constituents, have never heard of overshoot. Instead, popular interest swings with media attention among its various *symptoms* – climate change, plunging biodiversity, plastic pollution of the oceans, landscape and soil degradation, tropical deforestation, the SARS-CoV-2 pandemic – without connecting the dots. Even when commentators talk about the need for "multi-solving" they usually mean coordinated efforts to fight the diverse effects (intense heat-waves, extended drought, increasingly violent storms, unprecedented wildfires, rising sea-levels, accelerating forest die-back, etc.) of just one human-induced phenomenon, climate change.

Acknowledging EO is important because it is the *ultimate* meta-problem, the overlying proximate cause of all the other problems associated with humanity's ecological predicament. Biodiversity loss, air/land/water pollution, climate change, impending resource scarcity – pick your issue – all result from EO, too many people consuming excess energy/material and over-polluting their supportive ecosystems. We cannot "solve" any major symptom of EO, including climate change, in isolation from any other. Conversely, tackling EO directly would address all its symptoms simultaneously.

But here's the rub; by definition, the only way to "tackle" EO is by significant absolute reductions in energy/material consumption and human numbers.

Which brings us back to population projections, urbanization and the future of cities.

Most national governments and international organizations see the future as a technologically more advanced and socially more inclusive extension of the recent past. They acknowledge environmental problems, of course, but again the major focus respecting cities is on climate change. For example, the United Nation's Sustainable Development Goal #11, aims to "Make cities and human settlements inclusive, safe, resilient and sustainable" by, among other things, substantially "increasing the number of cities and human

settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change [and], resilience to disasters" (UN n.d.). Similarly, the C40 cities network, an association of 100 of the world's major cities is "working to deliver the urgent action needed right now to confront the climate crisis and create a future where everyone, everywhere can thrive." C40 city mayors "are committed to using a science-based and people-focused approach to help the world limit global heating to 1.5 C° and build healthy, equitable, and resilient communities" (C40 Cities 2021).

In short, neither the UN, the C40 network nor similar organizations acknowledge overshoot – overconsumption and overpopulation – and the attendant possibilities of significant resources shortages and widespread systems collapse. Modern techno-industrial (MTI) society radiates confidence in the ability of human ingenuity and technology to power through the ecological crisis however it might currently be defined. Climate change an existential threat? Not to worry – humanity's future hangs on belief that the transition to wind, solar and hydrogen electricity will enable a smooth transition to a zero-carbon economy, paving the way to a bountifully safe and sustainable future.

Socially Constructed Shared Illusions

What ordinary citizens don't appreciate is that human beings characteristically "socially construct" their own realities, or rather their *perceptions* of reality. Virtually everything we think we "know" – political ideologies, religious beliefs, disciplinary paradigms, cultural norms and even scientific truths – are products of the human mind, conceived in words and massaged into received wisdom through social discourse among participants in the exercise, whether they be street-wise villagers, priests or scientists. The two most important things to keep in mind about any social construct is that: (1) it may or may not contain an accurate "map" of any part of biophysical reality it purports to represent and; (2) accurate or not, people live out of their constructed perceptions *as if they were real*.

Why raise this issue here? Because it flags the possibility that mainstream understanding of economic/population growth and its implications for urbanization/cities is fatally flawed. Consider that the most prominent development-related social construct in play in the world today is growth-oriented neoliberal economics. Virtually all senior and local governments are in thrall of the double-barreled myth of infinite economic growth enabled by continuous technological development. This socially constructed narrative has birthed the conviction that climate change (remember, overshoot isn't part of the discussion) can be solved through human ingenuity – new technologies – and is therefore no impediment to maintaining the *status quo*.

The problem is that neoliberal economic models contain no useful information whatever about the complex structure and behavioral dynamics of the ecosystems and even social systems with which the economy interacts in the real world. This is a crucial failing. The first law of cybernetics (systems regulation) states that if we hope to maintain control, the internal variety or complexity of our management system must at least match the variety/complexity of the system being managed. Given our vacuous economic models, it should be no surprise that the ecosphere is increasingly in turmoil and that the evening news frequently features stories of mounting socio-political unrest. Neoliberal theory is already floundering; mainstream political and economic constructs are wholly incompetent to guide the future development of the human enterprise.

In this light, the purpose of this paper is threefold: first I describe just two dimensions of urban biophysical reality that are missing from mainstream thinking but essential to understanding prospects for cities in the twenty-first century. Second, I explore what including these elements implies for further urbanization and the future of existing cities in the context of climate change and the renewable energy (non)transition and; third, I outline an alternative settlement pattern that conforms to biophysical reality. This analysis and perceptual "reset" are sufficient both to explain why large cities and mega-cities may not

survive the twenty-first century and to stimulate the quest for alternatives consistent with one-planet living.

The Secret Life of Cities

Cities are many things; some conceive of cities as concentrations of people crowded into areas dominated by the "built-environment" (urban areas now comprise the principal habitat of *H. sapiens*). Others see cities as engines of economic growth; centers of commerce; seats of government; the loci of great universities and well-springs of arts and culture. Cities are, indeed, all of these things simultaneously – but something is missing. Not many urban dwellers or even urban scholars think first of cities as biophysical entities subject to the same natural laws and constraints as all other complex living systems.

This is a serious failing. The capacity of cities to function in their myriad ways depends utterly on the integrity of their biophysical relationships. Indeed, the state and fates of modern cities may well be determined as much by the operation of the law of conservation of matter and the laws of thermodynamics as by economic, social or political conditions (see Box 1).

Box 1 Fundamental Physical Laws and Concepts

- The law of conservation of mass dictates *that matter is neither created nor destroyed*, e.g., the mass (weight) of reacting substances at the beginning of a chemical reaction is precisely equal to the mass of new compounds at the end of the reaction. What goes in all comes out, albeit in altered form.
- The first law of thermodynamics is a restatement of the law of conservation of energy: energy is neither created nor destroyed. Thus, energy may be transformed from an "available" form (e.g., chemical energy in gasoline) into useful work (e.g., kinetic energy of the moving vehicle) plus a useless degraded form (e.g., heat radiating from the engine or dissipated in the exhaust), but the total quantity of energy remains constant.
- The second law of thermodynamics dictates that, with any change in an isolated system, the entropy (disorder, randomness) of the system always increases. In fact, *any real process increases the entropy of the universe*. The second law also implies that no energy/material transformation (e.g., chemical energy into useful work) can be 100% efficient. Some energy is always lost as low grade heat; matter "rusts," crumbles and disintegrates. Entropy increases.

Cities and the Basic Laws of Nature

Have you ever heard your home town referred to as a "dissipative structure"? Probably not – this is a term one would apply only if describing a city from the perspective of the second law of thermodynamics.

The second law states that any spontaneous change in the state of an isolated system (one unable to exchange energy or matter with its environment) increases the "entropy" of that system. This means that the system becomes more disordered – it loses structure and potential, concentrations disperse, available energy is degraded and dissipated as low-grade heat. In an isolated system, therefore, each successive event brings it closer to a state of maximum local entropy. This is a state of thermodynamic equilibrium in which *no further change is possible*. In the extreme case, all form and function is lost; matter would be randomly dispersed; no point in the "system" would be distinguishable from any other.

Of course, not all dynamic systems are isolated; exchanges with their surroundings are possible. Consider first the human body. Like other complex systems, our physical selves are subject to entropic decay; we are continuously wearing out under the dictates of the second law. However,

living systems are characterized by metabolic processes that seem to defy the entropy law. The human body is an "autopoietic" or self-producing system of sub-systems exquisitely structured to perform numerous biological and social functions simultaneously without running down. This is because healthy bodies are *open* systems, able to produce and maintain themselves in a *far-from-equilibrium* steady-state by importing highly-structured energy-rich material (we call it "food") from their environments. We use a portion of this imported energy/matter for repair and growth (self-production) but "dissipate" most of it back into the environment as bodily waste and low-grade heat energy.

Now consider "the city." In many respects, every city is a complex, highly-structured multi-functional super-organism. Indeed, various urban sub-systems – water and sewage, solid waste disposal, electricity and communications, streets and roads, inter-city transportation, etc. – are directly analogous to functionally similar human organ systems. Cities are also subject to second law erosion but, like our bodies, are open systems maintained by a compound metabolic process that is even more complex than our own. In addition to the collective metabolic demands of its human inhabitants, cities have an *industrial* metabolism. To grow or simply maintain themselves in a smoothly functioning operational state far-from-equilibrium, cities must import large quantities of low-entropy energy/matter. This includes all the food and fiber to satisfy the biological needs of their inhabitants, plus all the fossil and electrical energy, and all the raw materials, manufactured goods and equipment required to construct and maintain the built environment and supportive infrastructure. To this we must add the energy and material resources embodied in the appliances, tools, electronic gadgets, toys, and other artifacts of modern consumer society. One result of producing themselves is that cities necessarily generate prodigious quantities of material waste and low-grade heat energy all of which is "exported" – dissipated – into their ambient environments. It should be no surprise that cities account for 60–70% of global material consumption, expected to grow from 40 billion tonnes in 2010 to 90 billion tonnes in 2050 (IRP 2018). They also log up to 80% of global energy consumption and 70% of greenhouse gas (GHG) emissions. Cities are indeed archetypal "dissipative structures".

Of course, cities are not all thermodynamically equal. High-quality energy and resources (negentropy) are expensive. Wealthy consumer cities can therefore afford the maintenance costs of keeping material entropy at bay locally while exporting their second law dregs to rural areas and the global commons. By contrast, the crumbling buildings, run-down infrastructure and general squalor of impoverished cities bear witness to the relentless corroding effect of the second law when it cannot constantly be papered over. Such evidence of the entropy law at work accurately reflects the egregious wealth/income gap between rich and poor cities (and, for that matter, between rich and poor neighborhoods within cities). Keep in mind, however, that for all their glittery splendor, high-income cities actually impose a much greater per capita entropic burden on the ecosphere than do low-income cities. Extremes of consumption imply extremes of entropic dissipation.

In summary, cities thrive and grow by extracting negentropy (high-grade energy and resources) from their environments and exporting entropy (low grade heat and useless waste) back into those same environments, i.e., the ecosphere. However, because no energy transformation is close to 100% efficient, the price of any increment of urban growth, or even simple maintenance, is a much greater increase in the entropic disordering of the ecosphere. Indeed, the law of conservation of mass and the first law of thermodynamics (conservation of energy) ensure that 100% of the energy/material inputs imported to maintain or expand the city eventually joins the entropic waste stream. Simply put, *a little order over here (the city) means much greater disorder over there (elsewhere in the ecosphere)*.

All of which suggests another analogy. We can define a parasite as any organism that gains its vitality at the expense of the vitality of its host. It should be obvious from the foregoing description of urban metabolism that cities, as presently

conceived, exist in a potentially parasitic relationship with the rest of the ecosphere (Rees 2021).

Cities per se Are Inherently Unsustainable

Cities are generally perceived as productive wonders – economic powerhouses, founts of cultural creation, etc. – and in a strictly anthropocentric sense they are. However, we have shown that, from a biophysical perspective, all economic processes, cultural events, and other urban activities are mainly consumptive. This begs the question: if cities are mostly about consumption, who or what is doing the production? The short answer: the ecosystems that constitute the rest of the ecosphere.

Cities are themselves sometimes called ecosystems but are anything but. Complete ecosystems include: (1) producer organisms (mostly green plants); (2) macro-consumers (mostly multicellular animals, including humans); and (3) micro-consumers (bacteria and fungi). Green plants self-produce using extra-planetary solar energy to assemble biomass from carbon dioxide, water, and trace nutrients. Macro-consumers self-produce by consuming plants or other macro-consumers and micro-consumers self-produce by decomposing the bodies of both plants and animals and returning nutrients to the soil so the cycle can repeat continuously. In short, complete ecosystems are exquisitely complex quasi-independent systems that can maintain themselves and thrive "far-from-equilibrium" indefinitely by continuously transforming and recycling matter and assimilating and dissipating solar energy. The resultant waste heat is radiated off the planet which increases the entropy of the universe.

By contrast, cities are dominated by a single macro-consumer species, their human inhabitants. There are insufficient producers and decomposers to sustain the system, particularly if we factor in cities' industrial metabolism. Cities and their human populations can maintain themselves "far-from-equilibrium" *only* by assimilating and dissipating biomass (food and fiber), and fossil fuel and material resources imported from their extra-urban "environments." They "radiate" the resultant waste (pollution) back into those environments thereby increasing the entropy of the ecosphere. Clearly, cities per se are inherently unsustainable. Enclosed in an impermeable glass bell-jar (i.e., unable to exchange with its environment), any city would simultaneously starve and suffocate in its own entropic excreta in an inexorable descent toward thermodynamic equilibrium.

The Real Urban Human Ecosystem

We often hear that cities occupy only 2–3% of Earth's land surface. In ecological terms, such estimates are meaningless – they consider only the mostly lifeless built-up lands physically occupied by human settlements. A more relevant approach might be to ask "how large an area of productive ecosystems is necessary to support a given urban population at a specified material standard of living?" The answer to this question, combined with the built-up land, would constitute the area of that city population's de facto, functionally complete, ecosystem.

We can estimate this area using ecological footprint analysis (EFA). The ecological footprint (EF) of any study population – an individual to an entire nation – is defined as:

> the area of productive land and aquatic ecosystems required, on a continuous basis by that population, to produce the bio-resources that the population consumes and to assimilate its carbon wastes.

Numerous studies have shown that average human per capita eco-footprints range from over 10 global average hectares (gha) in rich countries to as little as half a gha in the poorest nations. Western European countries typically have EFs of 4–5 gha/capita; Canadians and Americans "enjoy" EF of ~8.1 gha; Japan's average per capita EF is 4.6 gha (see GFN 2021b).

We can readily show from these data that city eco-footprints are enormous. Indeed, the EFs of rich-country cities may be a 100 or more – even a 1000 – times the size of their geographic areas (Warren-Rhodes and Koenig 2001). Consider metropolitan Tokyo: with population of 37.3 million people (~30% of Japan's domestic population) and a per capita EF of 4.6 gha, the total eco-footprint of metro-Tokyo is

~171,580,000 gha. This is nominally 127 times larger than the city's metropolitan area of 1,350,000 ha. More telling, Japan's domestic bio-capacity is only ~75,600,000 gha, so *the EF of Tokyo alone is 2.3 times greater than that nation's entire productive area*. The residents of Tokyo are running a huge eco-deficit; they live, in large part, off the productive and assimilative capacities of ecosystems in distant countries and the global commons. So large is Tokyo's deficit that Japan could not support the population of just its national capital at current material standards if the country were cut off from the rest of the world.

It is worth noting in passing that humanity as a whole is running a massive ecological deficit but, unlike Toyko or Japan, cannot cover it through trade or natural material flows. Instead, we can (only temporarily) suspend the human enterprise far-from-equilibrium by depleting vital ecosystems, destroying non-human species and undermining global life support systems. Such are the consequences of overshoot. Also, while EF results may appear frighteningly extreme, they are typically underestimates for several technical reasons. For example, if data sets conflict, analysts typically use the more conservative numbers; not all waste streams are included in the EF; and the method estimates ecosystem areas-in-use but not whether such land/water use is sustainable (i.e., EFA does not account for ecosystem degradation or over-harvesting).

Bottom line: Cities may be where most people "live," but built-up areas constitute less than 1% of the functional human urban ecosystem. Each city is a compact node of intense consumption and energy/matter dissipation (i.e., pollution); the vastly larger and arguably more important productive and assimilative component of the urban ecosystem is the city's rural hinterland, the globally scattered aggregate eco-footprint of its human inhabitants. This reality remains largely out-of-mind – globalization and trade have isolated urbanites both spatially and psychologically from the ecosystems that support them. But the fact remains: no city could survive in the absence of distant supportive ecosystems. (By contrast the latter would thrive splendidly in the absence of cities.)

The Existential Threat to Cities

Modern cities and mega-cities exist because they can. No one sat down to plan a metro New York of 18 million people, a Shanghai of 28 million or a Tokyo of 37 million. These and like cities are truly "emergent phenomena" of the modern techno-industrial age, manifestations of humanity's explosive growth in the past two centuries. More than 300,000 years passed before the human population reached its first billion in the early nineteenth century. Then, in just 200 years, less than 1/1500th as much time, humanity expanded sevenfold and will top eight billion by 2023. This brief period of continuous growth and urbanization, a state that economists, politicians, and many ordinary citizens take to be the norm, is actually *the single most anomalous period in human history*!

It is a little known but crucial fact that this explosive anomaly was made possible by fossil fuels. Fossil fuels (FF) are a prodigious source of "negentropy," of potential and possibilities. Other factors, particularly, improving public health and longevity, contributed. However, it is fossil energy that made the modern world possible.

Modern cities and mega-cities in particular are the most spectacular products of FF. As already argued, abundant cheap energy was – and still is – necessary not only to "build out" our cities, but also to supply them with all the food, consumer goods, and low entropy materials needed to defend urban infrastructure against the corrosive workings of the second law. Consider that fossil fuels and petroleum-derived inputs (e.g., pesticides, fertilizers) inject ten times as much energy into agriculture and food processing as does photosynthesis and are thus crucial to food production. Stand on the sidewalk near a major construction site on a busy road in any city anywhere – the near-deafening din of excavators, cement mixers, dump trucks, and power tools of all kinds blending with the road noise generated by passing delivery and passenger vehicles is the sound of raw energy – mostly FF – at work (and being permanently dissipated).

Because cities are consumptive black holes, everything essential to cities' growth and maintenance – including all that that raw energy – has to

be brought in from cities' global EF hinterlands. Cities are therefore dependent for survival on the global and national marine, air and highway transportation networks that represent almost 20% of final energy demand, the bulk of which is provided by fossil fuels (see Friedemann 2016). Passenger cars are the largest energy hogs using 59% of transportation energy. Road freight accounts for another 27%, much of it to service cities. In the USA, for example, more than 80% of towns and cities are provisioned *only* by trucks; heavy duty diesel-powered Class 8 trucks haul 70% of the nation's freight. Air, rail, and marine transportation also contribute significantly, accounting for 7%, 2%, and 2% of transportation energy respectively.

The Climate Change – Energy Conundrum

Cities' profound dependence on FFs raises several issues bearing on the future of urbanization and urban life. First, the fossil-fueled expansion of the human enterprise has taken us well into potentially fatal ecological overshoot (EO). Without abundant cheap energy, the overexploitation of both ecosystems and non-renewable resources (including FFs themselves) would not have been possible. Second, FFs are a major source of carbon dioxide (CO_2) emissions. CO_2 is an unavoidable entropic product of fossil fuel combustion and the principal driver of the most obvious symptom of overshoot, anthropogenic climate change.

Atmospheric CO_2 and other GHG concentrations are increasing. The current trajectory implies 3–4 C° mean global warming in this century, far above the existing 1 C°+ warming that is already causing unprecedented climate havoc around the world. In recognition that even 3 C° warming spells climate disaster, parties to the United Nations Framework Convention on Climate Change committed in the 2015 COP21 Paris Agreement to hold the increase in global average temperature to "well below 2 C° above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 C° above pre-industrial levels" (IPCC 2018).

To meet the 1.5 C° challenge, carbon emissions (basically fossil fuel use) would have to be reduced by ~50% by 2030 on the way to full decarbonization by 2050 (Rockström et al. 2017; IPCC 2018). Some authorities argue that complete decarbonization must be achieved by 2030 (Spratt et al. 2020). (Meanwhile, the voluntary emissions reduction commitments – nationally determined contributions – made in Paris constitute only a third of the reductions needed to limit warming to even 2 C°.)

The Paris targets obviously pose an unprecedented challenge to a world primarily powered by fossil fuels. So-called modern renewable energy (RE), mostly wind turbines and solar PV, has made significant inroads displacing FF (mainly coal) in electricity production. However, in 2020, a year in which FF use and emissions actually declined by over 6% due to the CoViD-19 pandemic, FF still provided 83% of primary energy while wind and solar (where most investment in renewables is going) the equivalent of only 4.4%. FF even accounted for 61% of electricity generation while wind and solar provided only 9.1%, or less than 2% of total final energy consumption (data from BP 2021).

Any political leader who moved aggressively to cut FF use by the minimal 50% in this decade without viable substitutes and a comprehensive socioeconomic restructuring plan would be courting economic and political disaster. Most countries would suffer the pain of strict rationing of energy to essential uses, serious energy shortages and shrinking economies. With reduced services and goods production and the collapse of tourism, we would see declining incomes, rampant unemployment and rising inequality. Reduced agricultural output, combined with broken international supply lines and failing intercity transportation, would lead to local famines and global food shortages. The expected 60%+ expansion of cities (by 2050) could not occur; it would likely even be impossible to maintain large cities and mega-cities. Whither their existing populations? Civil disorder and geopolitical tension would rise perhaps to the breaking point. All would be complicated by continuing climate change – even if atmospheric GHG concentrations stabilize, there is already an additional 0.5 C° warming "in the pipe" due to the thermal inertia of the oceans.

All of which explains why global MTI society has taken an alternative course. Most senior governments, urban administrations, international organizations, many academic analysts and even environmental organizations have bought into a new mythic construct, the so-called green renewable energy (RE) transition as reflected in such concepts as the Green New Deal, the circular economy and green growth. Numerous promotional brochures and formal studies argue that falling costs and increasing efficiency make 100% renewable energy – mainly wind turbines and solar photovoltaics, but now also hydrogen – possible, by no later than 2050. "Net zero by 2050" (meaning no new manmade additions to atmospheric CO_2) is part of the new energy mantra. It seems we can eat the climate challenge and have our energy cake too – what's not to like?

Plenty, as it turns out. Most of these ebullient assessments are incomplete analyses that ignore important technical issues, material supply problems, land shortages, ecological and social impacts, and the overall scale of the exercise. Seibert and Rees (2021) review the evidence showing that modern REs are actually not renewable (merely replaceable); that their production from mine-head to installation is itself fossil-energy-intensive; that they cannot deliver the same quantity and quality of energy as FFs (in much of the world, there are inadequate energy returns on energy invested); and that their lifecycles entail egregious social injustice and significant ecological degradation. Moreover, according to Michaux (2021), there are simply not enough key material resources or time to replace the existing fossil fuel powered system with renewable technologies on the schedule set by the IPCC. Some climate scientists refer to net zero by 2050 as an illusion or dangerous trap that, at best, unnecessarily extends the FF era (Dyke et al. 2021; Spratt and Dunlop 2021).

Consider just one dimension of the scaling-up problem. In 2020, fossil fuels supplied 462.9 exajoules (Ej) of primary energy to the world. To displace 50% of this quantitatively with wind and solar electricity by 2030 implies constructing new wind and solar capacity sufficient to displace 25.7 Ej of FF energy *each year* for the next 9 years (231.5 Ej/9 years). If we (generously) assume a conversion ratio of 2.47:1 for wind and solar energy (i.e., one unit of wind/solar electricity = 2.47 units of fossil energy when converted to electricity), we would need to construct 10.4 Ej of new wind and solar generation capacity *annually* through 2030. But this increment exceeds the entire 8.8 Ej of wind and solar generation in 2020. In short, to replace just half of fossil fuel usage with electricity by 2030 would require that the world construct *every year* for almost a decade, more than the entire global multi-decade cumulative physical stock of wind turbines and solar panels (energy data from BP 2021). We must also assume that many difficult or impossible to electrify uses of FF will be electrified, that there is no need for the high-heat and other special qualities of FF in multiple end-uses, that the demand for investment capital in an already stressed market doesn't collapse the economy, and that there will be no growth in demand for energy. (In fact, analysts expect demand to grow by 40%+ by 2050.) This last is an important consideration – in recent years, growth in electricity consumption *alone* has exceeded new renewable supply, a problem that is anticipated to resume in 2021 as demand rebounds from the pandemic slump. A smooth transition away from fossil fuels is an impossibility theorem.

Just what is going on here? Mainstream governments, major corporations and their allies are behaving as exemplary discounters: they prefer to accept the uncertain risk of future catastrophic climate change which (they hope) will mainly affect other people somewhere else, rather than the immediate certain risk of economic and social chaos at home. Moreover, they are bound to seek solutions self-referentially from within the neoliberal techno-expansionist paradigm. Assertive policies that would actually work to reduce carbon emissions but create energy supply shortages or other threats to economic growth are inadmissible; population or family planning is still taboo; significant lifestyle changes are not on the table. The only politically feasible "solutions" to climate change – high-tech wind turbines, solar photovoltaics, hydrogen fuels, electric vehicles, and as yet unproved (and totally impractical) carbon-capture

and storage technologies all require major capital investment. These techno-fixes serve as stimulants for economic growth, provide well-paying jobs and generate opportunities for profit. However, far from addressing our eco-predicament, these technologies would extend the *status quo*. As Spash (2016) and others have observed, acceptable "climate action" makes capitalist growth economies appear to be the solution to, rather than the cause of, our ecological crisis. The mainstream is essentially promoting *business-as-usual-by-alternative-means*; this will not "solve" climate change and *does not even acknowledge overshoot*.

It also means, of course, that fossil fuel use will continue for years and decades to come (as long recognized by the International Energy Agency, the US Energy Information Administration, Canada's Energy Regulator, and similar national entities). Some argue that even the IPCC has long been politically motivated to underestimate the scale of the problem. Thus, contrary to the Paris Accord, there is no chance the world can avoid 1.5 C° mean global warming and we will likely see a potentially disastrous 2 C° increase by 2050. Indeed, a prudent course would assume *no remaining carbon budget* even for the 2 C° target (Spratt et al. 2020).

Why so? Because even 2 C° warming may well trigger irreversible runaway "hothouse Earth" conditions (Steffen et al. 2018). In coming years, we will see an ice-free Arctic Ocean, more rapidly melting permafrost, methane releases, an increase in wildfires, and other short-term positive feedbacks that could put climate change on steroids.

Even in the best case, the world can expect more and longer heat waves and droughts, more violent tropical storms, extended wild-fire seasons, accelerating desertification, water shortages, crippled agriculture, food shortages, rising sea levels, and broken supply lines. Coastal cities will be flooded and some may eventually be abandoned. Many other cities are likely to be cut off from food-lands, energy, and other essential resources with the breakdown of national highway and marine transportation networks; this alone would make urban life untenable. According to the recent *Environmental Risk Outlook 2021* (2021), at least 414 cities with a total 1.4 billion plus inhabitants, are at high or extreme risk from a combination of pollution, dwindling water supplies, extreme heat stress, and other dimensions of climate change.

From this perspective, it appears that the sun is setting on the era of urbanization – how can anyone think seriously that we can build out cities to accommodate an *additional* 2.5 billion people? (Using what source of energy?) Devoid of cheap energy and economically drained, existing large cities and megacities will succumb to the entropy law. No longer able to remain "far from equilibrium," or even feed their human inhabitants, they can only contract or be abandoned. Many will not survive the end of the century. In the more vulnerable parts of the world, severe heat and drought will render even rural regions uninhabitable. Various studies estimate there could be mass migrations involving one to two billion eco-refugees by mid to late century (see Baker 2021). Domestic chaos and widespread geopolitical conflict is inevitable.

In *Triumph of the City*, his paean to human achievement, urban economist Edward Glaeser (2011) posits that "If the future is to be greener, then it must be more urban. For the sake of humanity and our planet, cities are – and must be – the wave of the future" (p. 222). Ironically, the ecological catastrophe that Glaeser supposed cities could head off may, instead, stop urbanization in its tracks.

Missed Opportunity: Can We Still Achieve "One-Planet Living"?

The foregoing analysis shows that that neoliberal economics, the economic hand-maiden to expansionist capitalism, is a multi-flawed construct. It not only contains no "map" of biophysical reality, it is positively hostile to the ecosphere within which the real economy is embedded. Note, too, that neoliberal models of human economic behavior are also crude caricatures of the real thing. Regrettably, the global mainstream continues to live out of this destructively distorted constructed reality. The inevitable result is rampant

consumerism, eco-overshoot (EO), egregious inequality, and the pan-cultural delusion that technology can dissolve any constraints on growth.

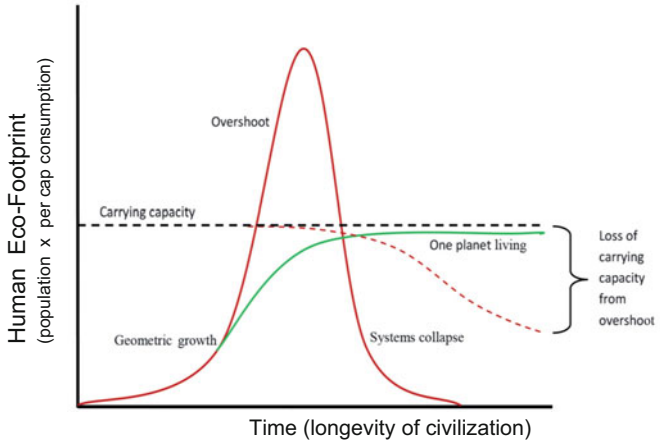
The aggregate symptoms of EO leave little doubt that the continuity of civilization – urban or otherwise – requires that the world community socially construct a new way of being on Earth, one that transcends MTI sensibilities. Confronting EO demands a conscious transformational paradigm shift, i.e., the abandonment of the foundational beliefs, values, and assumptions of neoliberal capitalism and their replacement with a framework that better reflects biophysical reality. This implies nothing less than a personal-to-civilizational metamorphosis from contemporary growth-obsessed juvenility to adult steady-state maturity. The goal would be a world in which fewer people can enjoy emotionally satisfying, materially sufficient lives in community without wrecking the planet. This is the essence of one-planet living – the balancing of population and material well-being within the regenerative and assimilative capacities (biocapacity) of Nature. Clearly, EO can be "solved" only through significant reductions in energy and material throughput (Fig. 1).

The quest for one planet living may be far too ambitious an undertaking for an over-crowded, competitive, increasingly fractious species in overshoot. Obviously, too, chances of success would be much greater had we begun the task a half century ago. Nevertheless, if humanity does not attempt such a pre-emptive correction, an overstressed ecosphere will impose its own painful solution.

Economy as Eco-Niche

Ecologists who study the material and social relationships of non-human species say they are mapping those species' ecological niches. An organism's "niche" describes its food, habitat and related resource demands and the role that the species plays in maintaining the function and structure of its ecosystem. Well-adapted niches are non-disruptive; they define the relevant species' economic relationships within, while contributing to the structural integrity of, relevant ecosystems. The time has come to redefine the human eco-niche – the material economy – so that *H. sapiens* becomes a harmoniously integrated component of the ecosystems that support our species on the only planet we have. (This and the immediately following sub-section are revised from Rees 2021.)

This vision suggests that one possible form of a new civilization might be a network of



Why Large Cities Won't Survive the Twenty-First Century, Fig. 1 The human enterprise is in overshoot, nearing the peak of a one-off population outbreak (solid red line). The cost of overshoot is a reduction of long-term carrying capacity (biocapacity). A more sophisticated civilization would have self-regulated to achieve "one planet living" (solid green line). The best our MTI society can do now is a controlled contraction that comes off peak and stabilizes at or below Earth's remaining biocapacity (dotted red line)

cooperative regional eco-economies supporting many fewer people thriving more equitably within the regenerative capacity of local ecosystems. For so "radical" a transformation to succeed, the denizens of MTI cultures must abandon and evolve beyond the core paradigm that defines their present way of being in the world.

To begin the metamorphosis, major national governments would formally have to:

- Accept the conceptual limitations of neoliberal economic thinking. In particular, we must abandon the myth of perpetual growth and our overweening confidence in human technological prowess;
- Acknowledge the need to reduce the human ecological footprint. As long as humanity remains in EO, sustainable production/consumption means absolutely less production/consumption;
- Concede the theoretical and practical difficulties/impossibility of a green, quantitatively equivalent, energy transition;
- Recognize that equitable sustainability requires economic leveling; i.e., we need fiscal and other regulatory mechanisms to ensure income/wealth/opportunity redistribution between and within countries – greater equality is better for everyone (Wilkinson and Pickett 2009);
- Participate in a global population strategy to enable a managed non-coercive, economically secure and cooperative descent to the one to two billion that could live comfortably indefinitely within the biophysical means of nature.

We will also have to resurrect other values that have been sacrificed to market capitalism. The cult of competitive individualism must concede to the need for cooperative collective solutions. A sense of unity with – or at least respect for – nature, recognition of material limits, loyalty to place, greater social equality, community cohesion, regional self-reliance and local economic diversity are all prerequisites for, long-term economic security, social well-being, and ecological stability. Above all, the new human eco-niche must be regenerative, i.e., the economy should be re-embedded in *local* community and that this (re)union developed as a fully-integrated mutualistic component of its sustaining ecosystems.

Those dubious of the beneficial pull of relocalization should consider the push factor. Globalization and unfettered trade – i.e., dependence on distant "elsewheres" for food and many other resources – will no longer be possible in the emerging resource and climate-constrained world. This is not entirely a bad thing. Globalization is a driver of overshoot – so-called free trade, particularly in the past half-century, greatly accelerated resource (over)exploitation and pollution, and facilitated population growth. It follows that adaptive eco-economies be more eco-centric local economies. Agriculture and essential light manufacturing – e.g., food processing, textiles, clothing, furniture, tools – will all be relocalized providing ample meaningful employment. There will be a resurgence of personal skills and pride in workmanship. As an immediate additional benefit, when citizens become acutely aware of their dependence on *local* ecosystems they become more actively concerned about the health and integrity of those systems. A sense of conscious participation in one's eco-niche is not possible if the relevant ecosystems are half a planet away.

"One Planet" Eco-Cities and Bioregions

> Localisation stands, at best, at the limits of practical possibility, but it has the decisive argument in its favour that there will be no alternative. (Fleming 2021)

Denizens of urban MTI society are generally unconscious of their individual eco-footprints or the extent to which their home towns and cities are dependent on productive hinterlands dispersed all over the planet. However, as we have shown, it will not likely be possible in coming decades to feed and otherwise provision large cities and megacities. Many urban populations will have to be dispersed and redistributed.

Most urbanites also forget that industrial energy now does the work that people and animals use to perform. Various studies show that people in high-income countries have the energy equivalent of hundreds of human slaves per capita in continuous employment providing them with the

goods and services they have come to take for granted. Some of this energy represents displaced draft animals. For example, the population of working horses and mules in the US peaked at 26 million in about 1915 – when the human population was about 100 million – only to be gradually replaced by fossil-powered farm and industrial equipment. The post-carbon US economy would once again need as many work-horses (and about 20 million ha – 50 million acres – of dedicated fodder-producing land) *even if the human population shrinks back from 331 to 100 million*.

Consistent with these data and the re-localization imperative, the following policies/objectives comprise just one example of how we might reconfigure present settlement patterns into more functionally self-contained urban-centered human econo-ecosystems. Senior governments should cooperate with regional and local officials to:

- Create national sub-systems of self-reliant bioregions or ecoregions *centered on existing smaller cities* with boundaries based on ecologically meaningful land-forms and biophysical features (e.g., watersheds, heights of land);
- Size each urban-centered eco-region initially to contain, where possible, a productive ecosystem area equivalent to its population's currently globally dispersed supportive hinterland; i.e., internalize their de facto eco-footprints. (As our example of Toyko revealed, there will be insufficient domestic land/water in many countries, forcing recognition of the need for much lower levels of material consumption and reduced populations.);
- Re-localize government services and decision-making authority, i.e., devolve sufficient governance and taxation powers to the new urban eco-regions to enable effective management of their internal resource- and ecosystems;
- Organize the regional economy and commerce to sustain the population as much as possible on domestic bio-resources and ecosystems, thus reducing reliance on trade. There will still be some trade but:
  - imports should be restricted to true necessities that cannot be produced locally;
  - exports should be limited to bio-resources in true eco-surplus, i.e., harvest rates must be less than regeneration rates to prevent natural capital depletion;
- Facilitate the organization of producer and consumer co-ops – every working person should have a genuine stake in the eco-economy. The ratio of highest paid management to average worker wages should be no greater than 5:1 (the average for Spain's well-known Mondragon cooperatives);
- Phase out trivial and non-essential uses of fossil energy (e.g., private automobiles, off-road vehicles, pleasure motor craft, jet skis, most snow-mobiles, and leaf-blowers);
- Allocate any remaining carbon budget (there may soon be none) to absolutely essential uses, for example, in agriculture and transportation;
- Invest in truly renewable energy sources: mechanical wind and water power; managed biomass, and in technologies that make efficient use of human and animal labor;
- Facilitate breeding programs to supply the draft horses and mules that will be needed to work the land, particularly in agriculture, as fossil-fueled equipment is phased out. Include approximately 0.8 ha (two acres) of forage-land per animal in the regional land bank (see second point above);
- Reintegrate animal husbandry with food-cropping in keeping with sound soils management and to reduce the need for artificial fertilizer with its associated ground- and surface-water pollution;
- Re-design urban waste management to convert settlements from resource-depleting throughput systems into self-sustaining circular-flow ecosystems. For example, collect, treat, and recycle animal and domestic nutrient-containing wastes onto the eco-region's farm and forest lands whence it came. (Circularity in nutrient flows is structurally and functionally necessary for any ecosystem's continuity.);
- Invest in natural capital restoration; regenerate depleted soils, degraded landscapes, wooded areas, and other wildlife habitats to promote

biodiversity, enhance regional productivity, increase carbon sink capacity, and mitigate climate change. (Human overuse has already dissipated half the world's topsoil but soil still contains several times as much carbon as the atmosphere.);
- Recognize that governance of regional ecosystems and landscapes for the common good will sometimes require stinting customary private property rights. Importantly, citizens who realize that their security depends on maintaining the integrity of local ecosystems have an incentive to support such measures.

Concluding Reflections

> Due to the power/interest structures of global capitalism and the juggernaut-like momentum of the global economy, it is most unlikely that any of the [proposed] radical changes to society and the economy. . . will be adopted in time [to avoid catastrophe]. (Dilworth 2010)

The adaptations to EO proposed in this paper run 180° from the capital-intensive growth-oriented "solutions" supported by governments, corporations, and international organizations anxious for the economy to come roaring back from the CoViD-19 pandemic. The mainstream vision is, however, fatally flawed. It is reductionist, narrowly focused on a solitary symptom of overshoot, ignorant of energy realities and devoid of biophysical insight. In particular, it acknowledges neither existing overshoot nor its roots in humanity's increasingly parasitic relationship with an increasingly turbulent ecosphere.

By contrast, the alternative above starts from EO and advances an adaptive approach to human ecological dysfunction that is wholly consistent with biophysical evidence and trends. The downsizing and re-localization of economic activities and their reintegration with communities and supportive ecosystems disaggregates the human enterprise into manageable spatial and eco-economic units consistent with the necessity of one-planet living. Most importantly, the transformation of modern *H. sapiens* from parasite on the ecosphere, to mutualistic participant in local ecosystems, represents humanity's ascent beyond even ecological literacy to lived experience.

Assuming that our best science is valid, the proposed approach clearly has the higher probability of successfully extending the longevity of civilization. However, there is as yet scant evidence that the world community or any individual nation is preparing voluntarily to embark on any form of deliberate long descent toward one-planet sustainability. Rather, it's full ahead on the RE transition and promotion of post-pandemic economic recovery. City administrations seem preoccupied with such marginally useful things as greener buildings, reduced carbon emissions from engineering operations, better public transit, enhanced green space, and "smarter traffic" control all of which, ironically, makes them more attractive to investment and growth. The circular economy (not wholly possible) and green growth (an oxymoron) are popular if somewhat delusional concepts for a society in overshoot. Certainly no city planning department has yet announced a scheme for the equitable contraction of the city's operations, the downsizing of its economy or the dispersal of its population. It is safe to say that no city or megacity on earth is remotely sustainable or even in managed control of its supportive ecosystems. On its present "developmental" path, global civilization is destined to have an interesting encounter with biophysical reality.

Is it too late to wake whole nations of sleepwalkers? Perhaps not. Increasing numbers of thoughtful citizens, activist organizations, and NGOs are taking to the streets. Politicians may yet be forced to take note; the kind of dramatic socioeconomic reset proposed herein may yet be within reach. As the human eco-predicament worsens, there is (shrinking) room for hope that there will yet be a grand popular awakening, one sufficient to catalyze the greater transformation needed to create a true global eco-civilization.

Dare we contemplate that *H. sapiens* can rise to full potential? Will our species rally and gift itself with the chance to take one more step up the evolutionary ladder?

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Wildfire

▶ Managing the Risk of Wildfire Where Urban Meets the Natural Environment