CITIES AS DISSIPATIVE STRUCTURES:
GLOBAL CHANGE AND THE INCREASING VULNERABILITY OF URBAN CIVILIZATION

William E. Rees, PhD, FRSC
UBC School of Community and Regional Planning
Washington State University
‘CARBON MASTERS’

Bellingham, WA – 10 November 2011
Starting premise: *H. Sapiens* is unsustainable by nature and nurture

### Base nature (genetic predisposition)

- Unless or until constrained by negative feedback, all species populations tend to:
  - *expand to fill all the ecological space accessible to them and*
  - *use all available resources (in the case of humans, to the limits of contemporary technology)* (Rees 2006).

### Careless nurture (cultural predisposition)

- Our socially-constructed myth of progress and continuous growth:
  - “*We have in our hands now… the technology to feed, clothe, and supply energy to an ever-growing population for the next seven billion years…”* (J. Simon 1995).
- The emergence of a new ‘age of unreason’
  - *E.g., politics dominated by neoliberal ideology, religious fundamentalism, climate-change denial, anti-intellectualism and other forms of ‘magical thinking’.*
In short, urban-industrial society is inherently unsustainable (Rees 2008)

- ‘Unsustainability’ is an inevitable emergent property of the systemic interaction between urban-industrial society, as presently conceived, and the ecosphere.
Ways to think of ‘the city’

- We usually think of cities as areas dominated the ‘built environment’ and characterized by high human population densities.
- Cities are hotbeds of artistic, cultural and political activity.
- Jane Jacobs trumpeted cities as the “engines of national economic growth.”

All this is true, but we usually forget that cities are also complex biophysical entities, i.e., open systems subject to thermodynamic law.
On the Second Law of Thermodynamics

As originally formulated:
- Any spontaneous change in an *isolated* system increases the system’s entropy (randomness, disorder); the system moves closer to thermodynamic equilibrium, a state in which nothing further can happen.

But we now recognize that:
- The same forces of entropic decay apply also to *open* systems. I.e., *all* things tend to run down wear out, ‘dissipate’—*including cities*. 
In this context, cities must be seen as far-from-equilibrium ‘dissipative structures’

- A **dissipative structure** is an organized non-equilibrium state of matter made possible and maintained by dissipative (energy consuming) processes.

- Dissipative structures grow more complex by importing exergy or ‘negentropy’ and exporting, or dissipating, entropy into their surroundings.
Modern urban ecosystems are also incomplete, ‘heterotrophic’ ecosystems

Enclosed in a bell-jar, any modern city would simultaneously starve and suffocate
Cities: The Consumptive Component of the Human Urban Ecosystem

- Cities are concentrated nodes of intense energy and material consumption and waste production—i.e., dissipative structures.

- The complementary, vastly larger, and increasingly global productive and assimilative component of the human urban ecosystem is separate from, and lies outside, ‘the city’. In short:

- Cities are *obligate* open systems that can self-organize and grow *only* by consuming, degrading and ‘dissipating’ available energy/matter (exergy) extracted from their surroundings (i.e., host ecosystems) and by dumping their wastes (entropy) back into their ‘hosts’.
Material Dissipation: Who Knew?
(dissipative processes are mostly hidden from view)

- Annual waste discharges from urban economies:
  Japan: 11 tonnes per capita. US: 25 tonnes per capita

- If we include material flows (soil erosion, overburden, construction debris, etc.) not actually used in production:
  Japan: 21 tonnes per capita. US: 86 tonnes per capita

- Both gross and per capita processed output (solid, liquid and gaseous discharges) are generally increasing even in the most efficient economies.

- The extraction and use of fossil energy resources dominate waste flows in industrialized countries. CO₂ is the greatest single waste-product by weight!
Degradation: Comparing ‘Natural’ and Human Ecosystems

Human-less ecosystems:

- Develop by degrading and dissipating solar exergy.
- Anabolic processes (production) exceed catabolic processes (degradation and dissipation).
- Biomass accumulates; species proliferate; complexity increases; stocks of available energy and matter (resource gradients) increase.
- Negentropy of ecosphere increases.
- Entropy of the universe increases.

Human-dominated ecosystems:

- Grow by degrading and dissipating Earth-bound exergy (including supportive ecosystems themselves).
- Despite growth in manufactured capital stocks, catabolism exceeds anabolism.
- Biomass (contemporary and fossil) is consumed and dissipated; ecosystems are simplified; biodiversity declines and functional integrity is lost; ‘resource stocks’ are depleted.
- Degraded waste accumulates in the ecosphere, entropy of ecosphere increases.
- Entropy of universe increases.
Earthly entropy: Alberta’s oil sands used to be boreal forest

Note the large warehouse or garage
Status of the Second Law

- “[Thermodynamics]...holds the supreme position among the laws of nature... If your theory is found 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” (Sir Arthur Eddington).

- “[Thermodynamics] is the only theory of a general nature of which I am convinced that it will never be overthrown” (Albert Einstein).
A population’s eco-footprint is the area of land and water ecosystems (biocapacity) required to produce the resources that the population consumes, and to assimilate the wastes that the population produces, wherever on Earth the relevant land/water may be located.

Alternately, think the eco-footprint as the area of natural photosynthetic solar collector (biocapacity) needed to generate the biomass equivalent of the exergy the population consumes, and to sequester the material entropy it produces in support of its life-style.
Eco-Footprints Vary with Income

- Average per capita EFs in high-income countries range between four and ten global average hectares (10 to 25 acres).
- The poorest people live on a third of a gha (.74 ac).
- There are only about 1.8 gha per person on earth.
- North Americans use 3-4 times their equitable share of global biocapacity.
A Measure of Success: Per Capita Ecological Footprints of Selected Countries
(2005 data from WWF 2008)

NB: Eco-footprints are exclusive areas—all people compete for Earth’s limited biocapacity.
Carbon emissions comprise the largest component of the ecological footprints of industrialized countries, generally ranging from two to four global average hectares.

CO2 – a dissipation product of fossil fuel use – is the greatest single waste-product by weight!
Ecological (Thermodynamic) Deficits: Living Beyond our Means

- Many countries ecologically ‘occupy’ a water- and land-base scattered all over the planet that is much larger than their domestic territories.
- Such countries are running ‘ecological deficits’ with other countries and the global commons.
- The human enterprise has already ‘overshot’ global biocapacity by up to 50%.
Biocapacities and Ecological Footprints of Selected Countries Compared to the World Averages (2005 data)

All countries that run eco-deficits are dependent on ‘surplus’ biocapacity (exergy) imported from low density countries (like Canada) and the global commons.
‘Modern’ cities are *all* eco-deficit
The twenty-nine largest cities of the Baltic states of Europe have an eco-footprint 565-1130 times larger as the cities themselves.

- Blocks on the left represent areas appropriated for bio-production.
- Blocks on the right represent productive area appropriated exclusively for waste assimilation (under two sets of assumptions).
The Ominous (but all too typical) Case of Tokyo

- Population: 33 Million (approx. 26% of Japanese pop)
- Total eco-footprint at 4.9 global ha/capita: 161,700,000 ha

Tokyo’s eco-footprint is about 344 times larger than the metro-region, 4.3 times the area of Japan and represents 2.1 times the nation’s domestic biocapacity.

What would Tokyo (or Japan) do if cut off from its global supportive hinterland?
In the context of global change:

‘Today’s city is the most vulnerable social structure ever conceived by man’ (Martin Oppenheimer).

Point: Cities will be increasingly threatened by the entropic degradation of the ecosphere:

- Soil losses and related resources shortages (e.g., peak phosphorus).
- Peak oil.
- Climate change (e.g., rising sea levels).
- Resultant geopolitical instability.
Urban Vulnerability 1: Landscape and Soil degradation

- Globally, topsoil is being “dissipated” 16 to 300 times as fast as it regenerates.
- We don’t notice because fossil energy is a soil substitute.
- Since 1967, fossil inputs—irrigation, mechanization and chemicals—have accounted for 79-96% of the increased yields of wheat, rice and maize.
Vulnerability 2: The Growing Discovery-Extraction Gap

Regular Conventional Oil
Source: ASPO, Sept 2008

Revisions backdated. Rounded with 3yr moving average.
Which leads to Olduvai theory—the short life-expectancy of industrial society

(Source: Richard Duncan 1997)
Vulnerability 3: Climate Change
(Atmospheric CO\textsubscript{2} increases 40% higher than expected since 2000)

Atmospheric CO\textsubscript{2} at Mauna Loa Observatory

- Rate of increase (ppm/year)
  - 1970-79: 1.3
  - 1990-99: 1.5
  - 2000-07: 2.3 (accelerating!)

Anthropogenic CO\textsubscript{2}:
Up 40% since early 19th Century

‘Safe’ is less than 350 ppm CO\textsubscript{2e}

NB: CO\textsubscript{2} is an entropic by-product of fossil fuel use

2011 level: 390 ppm
Result? Mean global Temp Up 0.8°C in 125 yrs

The upward trend continues: we’re at 0.8°C above 1880-1900 average, 0.5°C since 1970. 2005 is the current record but 2010 may exceed it.
And the heat goes on

- The first six months of 2010 were the warmest in the instrumental record. June-August was the fourth warmest such period on record.
- Depending on the strength of a developing La Nina, 2010 will be very close to the 12-month global temperature record (following 2005 and 1998).

N.B. we should be experiencing modest cooling—we are in the midst of the longest solar minimum (few or no sunspots) in many decades.
All of which turns the screws on the economy

- To stabilize GHGs at even 650 ppmv CO2e, the majority of OECD nations must begin to make draconian emission reductions (at least by 6%/annum) by 2015.

- 650 ppmv CO2e implies a catastrophic four degree C mean global temperature increase.

What reason Demands:

- Unless we can reconcile economic growth with unprecedented rates of decarbonization (in excess of 6%/yr), avoiding this increase will require a planned economic recession.

Is the world ready for hundreds of millions (billions?) of climate refugees?
Getting Serious about Sustainability: Necessary Qualities for Urban Resilience

- Appropriate scale (regional-scale ecosystems and watersheds are theoretically manageable; larger systems are not—c.f. Ashby’s law).
- Population below planning region’s carrying capacity.
- Steady-state regional economy (no material growth).
- Greater social equity and life-quality.
- Self-governing with control over as much as possible of its own resource base.
- Self-reliant (i.e., not self-sufficient but also not dependent on trade for vital supplies). Maxim: Trade if necessary but not necessarily trade).
- Multiple redundant energy/water/food sources; related redundant infrastructure (in particular, not fossil fuel dependent).
- Highly buffered food and water supplies (i.e., large storage capacity).
Toward Bioregional City-States: Ideal Design Goals

- Transform the city-nature relationship from parasite-host to symbiotic partnership by:
  - Reconceiving ‘the city system’ as complete human ecosystem (this is the ultimate in bio-mimicry). I.e.;
  - Consolidating as much as possible of the cities vital hinterland (its ‘eco-footprint’) near its urban core.
  - Reconfiguring the city from a resource-depleting throughput system to a self-sustaining circular-flows system.
  - Reintegrating living-space with economy; re-balanceing production and consumption.
  - Facilitating the reduction of residents’ ecological footprints to a globally equitable 1.8 hectares per capita. (thus achieving ‘quasi-sustainability’).
Is Such Eco-Transformation Possible?

‘The ecologically necessary remains politically unfeasible but the politically feasible is ecologically irrelevant.’
“Do we know what to do? Probably yes. Will we do it? Probably not.”