# A Safe Operating Space?
# Can We Measure It?
# Can We Maintain It?

By Richard W. Franke
Professor Emeritus of Anthropology: Montclair State University, New Jersey
Resident and Board Member: Ecovillage at Ithaca
Member of Sustainable Tompkins

With the growing awareness in the sustainability movement that earth's resource base is under stress and possibly in danger, we need to develop a framework and appropriate indicators to assess how much danger we are in and to identify those areas in which the crisis is more or less severe.

The September 24, 2009 issue of *Nature* summarized a study drafted by Johan Rockström of the Stockholm Resilience Centre and co-authored by 28 internationally known scientists. The article is entitled: A safe operating space for humanity. It also appeared in a longer form in the journal *Ecology and Society* [see end of this note for links].

**The Big Idea Behind the Article**:

- Humans as a species and human civilization developed within a certain range of variation in the values of the elements of the earth's life support system

**The Findings and their Implications:**

- We can identify [at least] nine components of the earth's life support system that are critical to human civilization
- These nine components have boundaries [limits] beyond which the life support system might cease to function properly – "non-linear events" [also called "ecological surprises" in some other studies, RWF] are likely to occur for which we might not have adequate responses
- We can [in principle] develop quantitative measures of where the boundaries are
- In this article, the authors propose boundaries for seven of the nine components
- We have already crossed the boundaries for three of the nine components
- We are therefore testing the boundaries of our life support system and need to develop policies to counter present trends

## The Nine Planetary Boundaries

The scanned-in chart below shows the nine indicators and their boundaries. This chart shows that humans have currently pushed beyond the boundaries for climate change, biodiversity loss and amount of reactive nitrogen. These are highlighted in red. On the next four, we are nearing the proposed boundaries. On two earth-system processes – atmospheric aerosol loading and chemical pollution–the authors were unable to determine an appropriate boundary. [Note: one complication of the chart is that the nitrogen and phosphorus cycles are considered as one process but they show as two. For this discussion I propose to ignore the phosphorus cycle.] The spider web figure just below and to the right gives a graphic picture of the current status of the earth's main biophysical resources. It shows in green where the boundaries are and in red where the boundaries have been breached or are being approached.

**PLANETARY BOUNDARIES**

| Earth-system process | Parameters | Proposed boundary | Current status | Pre-industrial value |
|---|---|---|---|---|
| Climate change | (i) Atmospheric carbon dioxide concentration (parts per million by volume) | 350 | 387 | 280 |
| | (ii) Change in radiative forcing (watts per metre squared) | 1 | 1.5 | 0 |
| Rate of biodiversity loss | Extinction rate (number of species per million species per year) | 10 | >100 | 0.1–1 |
| Nitrogen cycle (part of a boundary with the phosphorus cycle) | Amount of $N_2$ removed from the atmosphere for human use (millions of tonnes per year) | 35 | 121 | 0 |
| Phosphorus cycle (part of a boundary with the nitrogen cycle) | Quantity of P flowing into the oceans (millions of tonnes per year) | 11 | 8.5–9.5 | ~1 |
| Stratospheric ozone depletion | Concentration of ozone (Dobson unit) | 276 | 283 | 290 |
| Ocean acidification | Global mean saturation state of aragonite in surface sea water | 2.75 | 2.90 | 3.44 |
| Global freshwater use | Consumption of freshwater by humans ($km^3$ per year) | 4,000 | 2,600 | 415 |
| Change in land use | Percentage of global land cover converted to cropland | 15 | 11.7 | Low |
| Atmospheric aerosol loading | Overall particulate concentration in the atmosphere, on a regional basis | | To be determined | |
| Chemical pollution | For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof | | To be determined | |

Figure 1: Planetary Boundaries

### Boundaries Crossed

Let us consider briefly the three areas in which the authors indicate that the

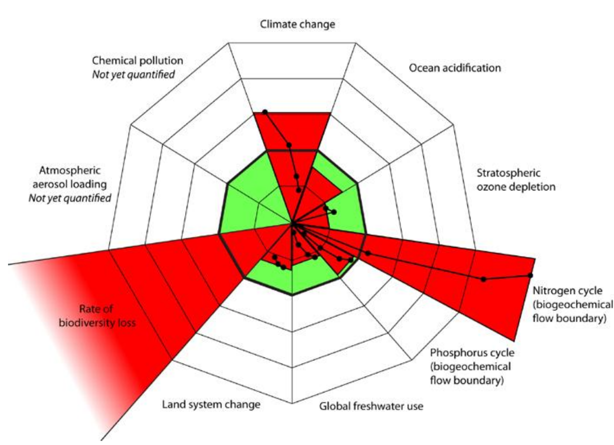





Figure 2: Boundary Crossings

boundaries have been crossed. If the article is correct, these would be the areas of top priority for activists to work on.

**Climate Change**: the authors justify the boundary of 350 parts per million (ppm) of $CO_2$ in the atmosphere based on paleontological research indicating that earth was ice free when ancient climates were in the range of 350−550 ppm. Invoking the precautionary principle, they argue we should set the boundary at the lower end of the range. **Should we discuss the precautionary principle in a future blog?** Among the consequences of breaching the 350 ppm boundary, the authors mention: retreat of mountain glaciers, loss of ice from Greenland and from the West Antarctic ice sheets, loss of Arctic Ocean ice, sea-level rise, bleaching and mortality of coral reefs, pole-ward shift of subtropical regions, rise in number of large floods and weakening of the oceans' ability to absorb carbon. In his book *Plan B 4.0: Mobilizing to Save Civilization* , (which can be downloaded free by clicking the highlighted text), Lester Brown adds numerous items to the list of potentially harmful outcomes: rapidly changing habitats leading to loss of species and thus decline of biodiversity, flooding of coastal cities around the world that could generate over 600 million climate refugees, loss of mountain glaciers on which many of the world's people depend for river water for their farms, severe declines of grain harvests from high-temperature-induced photosynthesis shock and pollination failure, intensified droughts in already dry areas and increases in storms in traditionally wet areas (see especially pages 55 – 71). Much of the East Coast of the U.S. would be pushed inland.

**Can we identify any specific consequences of climate change that have actually taken place in or around Tompkins County? What are the predicted or predictable consequences of likely changes over the next few decades? Do we need research on this? Would this be suitable for a future discussion?**

**Biodiversity Loss.** By far the threshold most seriously breached is that of biodiversity. The spider graph on page 2 shows that biodiversity loss goes off the scale. The authors used paleontological evidence suggesting an average natural rate of one extinction per million species per year. Current rates are thought to be greater than 100 while the upper boundary should be about 10. These may be conservative estimates. The authors note that previous accelerated extinction rates had taken place mostly on islands whereas current rates are occurring on the large continents. Overall, the authors estimate that 25% of all species in well studied taxonomic groups are threatened with extinction. The consequences of a major reduction in biodiversity are difficult to specify. However, a general thesis within biology and ecology is that lower diversity systems are more vulnerable to disturbances. Biodiversity provides various services to natural systems, some of which only occasionally come to mind – such as the pollination services that bees provide to agricultural production. A useful overview of the reasons to maintain biodiversity at the highest possible levels can be found on the global issues website. A more detailed and formal scientific analysis appears on the Stanford Encyclopedia of Philosophy page. **Do we have any information about biodiversity and/or**

**biodiversity loss or threats in the Tompkins County area? If so, what appear to be the most threatened species and what steps seem possible to take to lower the threats?**

**PS: The UN has designated 2010 as "Biodiversity Year."**

**Reactive Nitrogen.** The authors suggest limiting the conversion of nitrogen from the atmosphere to the soil at 25% of the naturally converted amount of land- and water-based nitrogen. Nitrogen exists as a gas in earth's atmosphere and makes up 78% of the gases present from the surface up to 18 km (11 miles). This is shown on the graph below.

While in the atmosphere, nitrogen is considered "inert." As a liquid or solid, however, some forms can react with other chemicals: thus the term "reactive nitrogen."

Humans create reactive nitrogen by:

- Spreading the cultivation of leguminous crops
- Burning of biomass
- Fossil fuel combustion
- The Haber-Bosch industrial nitrogen fixation process

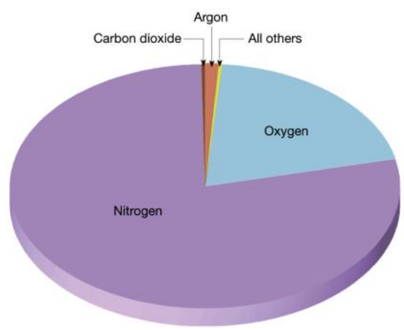
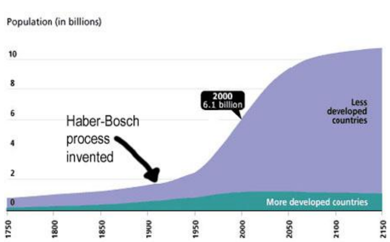



Figure 3: Gases in Earth's Atmosphere

Of these, the most important is the Haber-Bosch industrial fertilizer system. In 1909 German chemists Fritz Haber and Carl Bosch invented a way to turn atmospheric nitrogen into a form that could be applied as liquid or pellets on agricultural fields. This nitrogen vastly increased crop yields. Many scientists consider the Haber-Bosch process to be among the most important discoveries of the 20th Century.

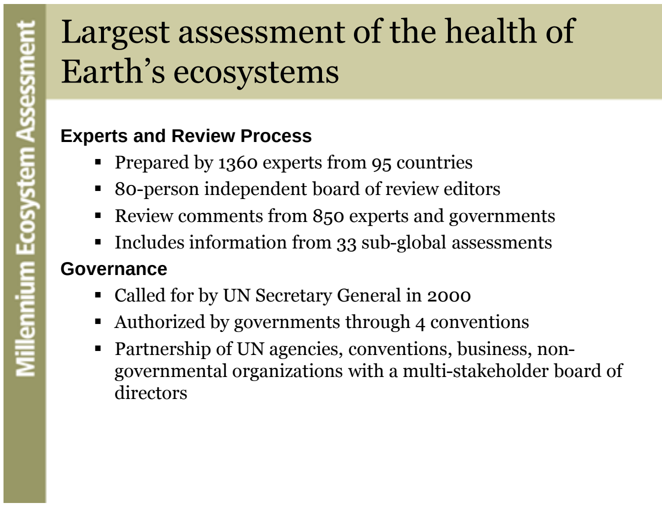
Some observers claim that up to 40% of all humans are alive today only because of Haber-Bosch http://www.idsia.ch/~juergen/haberbosch.html http://www.wisegeek.com/what-is-the-haber-bosch-process.htm




Haber-Bosch currently generates more than 500 million tons of nitrogen fertilizer while utilizing 1% of the world's total energy budget – mostly natural gas burned in the chemical alteration process. One-half of all nitrogen fertilizer used today is made from the Haber-Bosch process.

**Consequences:** The 2005 Millennium Ecological Assessment (MEA) considered reactive nitrogen one of the most serious environmental threats to the entire earth's life support system.

MEA Synthesis: "Since 1960, flows of reactive (biologically available) nitrogen in terrestrial ecosystems have doubled, and flows of phosphorus have tripled. More than half of all the synthetic nitrogen fertilizer, which was first manufactured in 1913, ever used on the planet has been used since 1985."




Reactive nitrogen is apparently the main cause of ocean "Dead Zones." When it combines with oxygen – as in cow manure – it becomes nitrous oxide, a powerful greenhouse gas. Other effects of reactive nitrogen identified by the MEA:

eutrophication of freshwater and coastal ecosystems (the mechanism for creating dead zones)

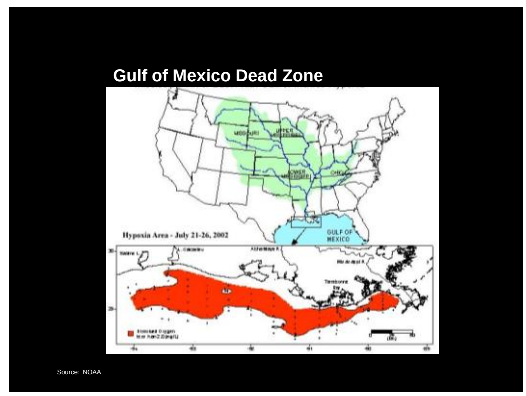
- contribution to acid rain
- loss of biodiversity

Contribution to:

- creation of ground-level ozone

destruction of ozone in the stratosphere

- contribution to global warming




Resulting health effects:

- consequences of ozone pollution on asthma and respiratory function
- increased allergies and asthma due to increased pollen production
- risk of blue-baby syndrome
- increased risk of cancer and other chronic diseases from nitrate in drinking water,
- increased risk of a variety of pulmonary and cardiac diseases from production of fine particles in the atmosphere


**Is the high profile of reactive nitrogen in the threats to the earth's life support system a surprise to you? Does awareness of it change your ideas in any way about what should be the priorities for Sustainable Tompkins?**

**Alternatives to reactive nitrogen and scientific and ethical dilemmas.** Since the first mass production of industrial nitrogen in 1913 world food production has rocketed. Any significant restrictions on the manufacture and use of industrial nitrogen pose questions about the security of the world's food supply and the issue of whether it is morally acceptable to take measures that might undermine access to food by large numbers of people. Is there a way out of this dilemma?

Organic farmers typically choose organic nitrogen, or, nitrogen that was created as part of the earth's natural nitrogen cycle. Organic nitrogen is more stable – less reactive – than industrial nitrogen. At a local level within Tompkins County, we could say that as the percent of land under organic production increases, the effects of reactive nitrogen locally would decrease. **Can organic farms produce the same levels of output as more industrially oriented farms that spread Haber-Bosch nitrogen on their crops?**

Two recent studies suggest that organic farming can achieve yields equal to farms that make widespread use of industrial chemicals, though it is not entirely clear if this refers to industrial nitrogen. Catherine Badgley in the Department of Ecology and Evolutionary Biology at the University of Michigan – and seven colleagues – published a paper in 2007 with farm level data suggesting that organic farming can equal or surpass industrial farming – at least for vegetable production.

(Her paper is summarized and discussed in Anna Lappé. 2010. *Diet for a Hot Planet: The Climate Crisis at the End of Your Fork and What You Can Do About It.* New York: Bloomsbury. Pp. 165–173.)

One of their main conclusions: "Data from temperate and tropical agroecosystems suggest that leguminous cover crops could fix enough nitrogen to replace the amount of synthetic fertilizer currently in use." This remarkable finding might surprise the general public, much of which still considers organic food as expensive and alien (only 3.5% of Americans eat organic). Lappé cites a study by University of Essex researcher Jules Pretty that found increases in output in many crops when grown organically. These studies suggest that industrial reactive nitrogen might not be as necessary as the public is lead to believe: Anna Lappé calls our misunderstanding about this "the hunger scare." One consequence of this finding seems to be that we are on the right track in the Tompkins County area in trying to spread organic farming: in addition to several other benefits, the more farmland under organic production the less reactive nitrogen we are spreading into the environment.

**Questions for discussion – follow the blog input instructions and submit your comments for everyone to read and respond to –**

1. Do you find the concept of "a safe operating space" useful as a part of thinking about sustainability? Are there other concepts that seem more suited to the work you are doing in Sustainable Tompkins or other related organizations?

2. Are there earth processes other than the nine identified by the authors that you feel should be added as indicators of whether we are undermining sustainability?

3. Assuming you agree with the authors, does their finding that climate change, biodiversity loss and excess reactive nitrogen have any impact on the work you are doing or does it make you wonder if you should shift your priorities?

4. Are there other aspects of the article not covered in the questions above that you feel should be addressed?

5. For the future, are there other subject areas which you would like me to try to prepare for a discussion similar to this one?

6. Or, would you prefer to develop a discussion document yourself?

## Read it yourself – click on highlighted text below for:

The 4-page short version as published in *Nature* 461:472-475, 24 September 2009

The 33-page full article as published in the online version of *Ecology and Society* 14(2), 2009

Appendix with supplementary discussion of some technical issues in quantifying boundaries

Stockholm Resilience Centre Annual Report for 2009 with info on impact of the paper on international scientific discussions

On the Earth Policy Institute webpage you can download for free the entire book –
Lester Brown. 2009. *Plan B 4.0: Mobilizing to Save Civilization*. New York: W. W. Norton
Chapter 3 – Climate Change and the Energy Transition – pages 55–71 – contains information relevant to this discussion.

---

Sustainable Tompkins Blog Topic #1: The Sustainable Tompkins Blog (STB) is intended to give sustainability activists an opportunity to think about and discuss scientific, ethical and political issues connected with our work but for which we often lack the time to read in depth. Volunteer bloggers prepare a short theme paper approximately monthly on a topic that might be of interest to the rest of us who chime in with our responses. If you want to submit a theme paper, contact Gay Nicholson at: gay@sustainabletompkins.org.