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Page

> Humans remain a myth-bound species that is capable of astonishing feats of self-delusion. The dominant cultural myth today promotes a materialists' vision of global 'development', characterized by unlimited economic expansion and fuelled by open markets and more liberalized trade.
>
> William E. Rees, *Nature* Vol 421, p.898, 27 February 2003.

The Optimum Population Trust (UK): Manchester

<www.optimumpopulation.org> & <www.members.aol.com/optjournal>

INTRODUCTION

The October 2002 issue of the *OPT Journal* demolished the 'carbon absorption paradigm' insofar as no one was able to mount significant arguments in its defence. And thus, in that issue, the 'renewable energy paradigm' was enthroned in its stead. This issue of the journal covers another aspect of eco-footprinting, namely the more philosophical ethical question of whether nations, individually, should live within their biocapacity. Although it is a less technical question, it is of equal importance.

There are seven valuable contributions to this debate (pp. 6-14). They all endorse the need for nations to live within their biocapacity. No degree of encouragement could stimulate anyone to defend a contrary position, a circumstance which I attempt to explain in my *Overview* of this Part II of the *2nd Footprint forum* (pp. 15-17). However, the reasons are less important than the fact that the outcome appears to conform with what I predicted in OPTJ 3/1 (p. 29): "I see *Part II* of the forum being similar to *Part I*, insofar as the truth of the matter is perfectly obvious, but it still requires an overwhelmingly clear exposition of the situation in order to get people to change their preferred way of looking at things." A necessary qualification to that is that no amount of evidence would change the minds of some people, as James Duguid points out (p. 9).

One of the great problems of renewable energy is that virtually all forms of renewable energy — and *all* forms which have a high net energy-capture (amount of energy that can be captured per hectare) — are intermittent. The only form of renewable energy which can follow demand, that is can be made available as occasion requires, is energy derived from biomass. Since this is not self-evident, Edmund Davey probes the subject, on pages 18-20.

Pages 21-27 follow up the brief article *Verdict on the Hydrogen Experiment* (OPTJ 2/1, p. 9), with a more comprehensive assessment, this time with a main focus on fuel cells, while not losing sight of the possibility of burning hydrogen in an internal combustion engine. It becomes manifest that hydrogen is only a solution to energy problems in rare places; indeed perhaps only in Iceland, with its abundant energy from hydroelectric and geothermal sources. However, since this conclusion is not something that comes at all easily to those who wish to believe that hydrogen is the answer to our future need for energy, the next issue of this journal will contain two further pieces on hydrogen, namely *Hydrogen Fantasies* and *Hydrogen as an Energy Carrier*. The title of the last piece brings out the most important fact, one which is often mentioned but rarely taken into account, namely that hydrogen is not an energy source, but only an energy carrier. Incidentally, drafts of those papers are already on the OPT Journal website (www.members.aol.com/optjournal).

Almost as difficult as getting people to fully appreciate that hydrogen is only an energy carrier is to persuade people that the world is emitting *more* than just a bit too much carbon dioxide: rather, we are emitting two and a half times what we might emit and still have a chance to eventually stabilize the atmospheric concentration at 1990 levels. *The Crucial Limit: 11 cubic km of Carbon per Decade* (pp. 28-31) tries to get the message over unequivocally.

James Duguid, of OPT, makes a contribution to the forum, and contributes again to the last page of this issue, with extracts from some of the many cuttings that he has taken from newspapers (which often, though not here, include letters that he has succeeded in getting published).

As usual, I am much indebted to David Pimentel who somehow finds time to look at all my output and make valuable comments. Thanks are also due to the contributors to the forum, and to Edmund Davey, Rosamund McDougall, and Yvette Willey.

A 2nd FOOTPRINT FORUM, PART II: ETHICS OF CARRYING CAPACITY

Introduced and mediated by Andrew R.B. Ferguson

An eco-footprinter may legitimately argue that Ecological Footprints are only a *measure*, and argue that eco-footprinters should refrain from recommending an ethical basis for using Footprints for fear that confusion may arise between the task of *measuring*, and the task of making use of the measure. Ethical principles belong to the realm of sociology, and so, most would say, lie outside the boundaries of science. It could be argued, too, that with respect to ethics the opinion of eco-footprinters is of no greater worth than of others, and that their opinions are of less value than those of historians, psychologists, and anthropologists. Despite all these legitimate objections, this *Part II* of the *2nd Footprint forum* will endeavour to discover the ethical stance on eco-footprinting of those most concerned with eco-footprinting. The chief justification for doing this is that, in practice, *eco-footprinters do not always desist from indicating their ethical assumptions*.

Let us look at some examples, starting with two exceptions, in that they do decline to express any judgement. Rees (2000:373) says, “It is important to note, that a properly constructed analysis is not itself ideologically biased toward any particular solution, technical or social, to the problem.” Also, in the *Living Planet Report* (WWF, 2000:13), Wackernagel et al., after noting the overshoot of biocapacity, say:

> Does this mean that people should live within the world’s average biological capacity, or their national biocapacity? Footprint calculations do not answer these questions, but try to quantify the ecological challenges and conflicts humanity needs to resolve if it wants to achieve global sustainability.

But a didactic voice can also emerge from the same author; for example Wackernagel and Yount (2000:35) made these observations:

> There is an average of only 2.1 biologically productive hectares per person on the globe. And assuming that setting aside 12 percent of the total area will suffice to secure biodiversity, the per-capita availability decreases to 2 ha. Population growth and ecological deterioration are reducing this area even more. The most crucial question for a sustainable world, therefore, is: how to secure an attractive quality of life out of less than 2 ha per person. Experiments and case studies are required to highlight this question and show how one can best live within these limits. . . . In preparation for a world population of 9 billion by the middle of the 21st century, we may even want to look for examples of high quality of life on less than 1 ha per person.

Few could fail to conclude that, according to these authors, an ethically sound — and presumably they think realistic — way of using eco-footprinting is to divide up the global biocapacity equally between the number of inhabitants on Earth, aiming to reduce Footprints to match. Perhaps this is the point at which to remind ourselves, that although ethical judgements are a matter of choice, they are somewhat circumscribed according to what is remotely plausible — taking human nature into account.

Some eco-footprinters are willing to state which ethics they *reject*, even if they will not say which ethics they support. For example, van Vuuren and Smeets, in responding to *Comments on eco-footprinting* (Ferguson, 2001), said:

> Ferguson argues that every nation, or perhaps group of nations, should live within its own ecological capacity. This is a specific elaboration of the sustainability concept, which we do not share and which is far from mainstream thinking.

In the following, Wackernagel and Silverstein (2000:393) indicate what it is that "mainstream thinking" rejects (italics added):

> National footprint comparisons have been the most controversial applications. Some insist that comparing a nation's footprint to its ecological capacity is not useful (McLaren 1999, Van den Bergh and Verbruggen 1999). *Indeed, it is fascinating how consistently people reject the idea that the ecological capacity of their territory represents real limits.* Probably their rejection is based on the common assumption that economic expansion is a given with the consequence that all countries will eventually need to import ecological capacities. *However, it is physically impossible for every country to be a net importer of biocapacity.*

Wackernagel and Silverstein do not state outright that nations should live within their biocapacity, but by showing the dangers of the opposite view they imply it. We see, therefore, that the situation is confused, with some eco-footprinters indicating an unwillingness to promote any ethical standpoint, others being prepared to hint at one, albeit not entering into any debate as to whether it is realistic, and others willing to state which ethical standpoint they reject, while not making any suggestions for a possible alternative.

The subject cannot be resolved by science alone. The debate will have to be guided by a knowledge of human nature and what will actually work in practice. So let us state clearly the subject of the debate: should the ethical basis for using Ecological Footprints be that each nation should live within its biocapacity? If not, then what should the ethical basis be?

Experience teaches me that "mainstream thinking" is a rather woolly belief that there are no national constraints, only a global constraint. The latter option would surely naturally lead to uncomfortable consequences, with some nations expanding to a point where they must decant their excess population, or appropriate the biocapacity of other nations; those who espouse such a policy need to explain how such consequences are to be avoided. So as to maintain as much clarity as possible, let us consider precise instances, albeit hypothetical ones. Taking data from the *Living Planet Report* (WWF, 2000), let us bear in mind, during the course of this debate, the following three scenarios:

a) Netherlanders maintain their present per capita Footprint and population size, thereby remaining in a state of overshooting their biocapacity by a factor of 1.4.

b) Netherlanders maintain their present per capita Footprint, while their population multiplies by 10 times; whereupon they overshoot their biocapacity by a factor of 23.

c) Chinese citizens increase the size of their per capita Footprint to that of today's Netherlanders, while China's population increases by 50%; whereupon they overshoot their biocapacity by a factor of 9. Note this would have the effect of China appropriating 80% of the Earth's biocapacity, with a population amounting to 30% of the world's present 6 billion.

In the above, it is only the *changes* in population and footprint size which are hypothetical. While the parameters chosen are not likely to be true, they are possible, and therefore a useful basis for discussion of principle.

It is clear that every nation has a tendency to expand its population beyond the bounds of its biocapacity, provided it has the wealth to do so. There could be no better example of this than the oil-rich nations, for which Youngquist (1997:404) gives these annual population growth rates:

Kuwait 6%.
Quatar 6.5%.
United Arab Emirates (UAE) 7.3%.

Note, incidentally, that at the UAE growth rate, it would take only 33 years for the population to grow to ten times its present size. The Netherlands is unlikely to match the UAE growth rate, but, given time, the feat of multiplying their population by ten is not beyond the bounds of possibility.

Note, too, that only nations can take control of their population growth. That it is possible for them so to do is shown by the examples of China, Iran and Bangladesh.

Thus it seems unavoidably clear that, without the ethical principle that 'nations should live within their biocapacity', disaster is bound to occur, which leaves those who reject this principle to propose some other ethical rule which might work. The least that should emerge from this forum is to find out if *anyone* can propose an ethical basis for using Ecological Footprints, which is politically realistic, other than that nations should live within their biocapacity.

Who have we invited to join the forum? First, all those who were invited to respond to *Part I*, but, as we observed, eco-footprinters may adopt a 'defensive position'; they may argue that other people are better fitted to address the question. Indeed, anthropologists and psychologists do have a rather better claim to relevant knowledge, so we have invited Virginia Abernethy and Kevin MacDonald, respectively the past and present editors of *Population and Environment*; J. Kenneth Smail, anthropologist and author of several papers on population. Colin Campbell, author of *The Coming Oil Crisis*; William Stanton, author of the recently published, *The Rapid Growth of Human Populations 1750-2000*; David and Marcia Pimentel, authors of *Food, Energy, and Society*; James Duguid, author of the booklet, *Population, Resources, and the Quality of Life*; Val Stevens of *OPT*; Jill Curnow of *Sustainable Population Australia*; and Edward Goldsmith, founder editor of *The Ecologist*.

We also invited nearly all those who have previously written on eco-footprinting (their names will appear in the final summary). Representing those who insist that comparing a nation's footprint to its ecological capacity is not useful is Jeroen van den Bergh (Van den Bergh and Verbruggen 1999), and the slightly more ambivalent Detlef van Vuuren. That is a brief introduction to some of those who were invited to respond.

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CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From Colin J. Campbell, Oil Depletion Analysis Centre, London
Staball Hill, Ballydehob, County Cork, Ireland

Figure 1, taken from my paper *Petroleum and People* (Campbell, 2002), provides a ready answer to the question that we are asked to address in the *2nd Footprint forum, Part II*. From a world population of 7 billion, around the middle of this century, population is likely to reduce to the region of 3.5 billion by 2200 (due to scarcity of energy). This represents a population decline of about 0.5% per year, over a hundred and fifty year period. It is surely beyond belief that every nation will see the writing on the wall, and thus start without delay to reduce their populations to a level which could be sustained on the lower energy levels which are likely to be available in the future. It thus behoves every nation to consider how it can best prepare for what is bound to be a very difficult transition period in human history.

Beyond question, large economies can be made in the use of energy for such things as transport and heating. Acting in the opposite direction, there will be a greater demand for energy both to extract coal and other fossil fuels, and to win materials from ores of declining concentration. The smoothest path to follow, through the difficult years ahead, surely lies in a more economical use of energy, combined with a slowly declining population. That is a path which some nations may have the wisdom to go down, but not, I would be prepared to wager, many.

Reference

Campbell, C.J. 2002. Petroleum and People. *Population and Environment*, Vol 24, No 2. pp. 193-207.

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[The Figure is available only in hard copy]

Figure 1. Population (each source of energy supports a corresponding population.
The impact on population of oil and gas has been dramatic but short-lived).

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From Jill Curnow of Sustainable Population Australia.
Barcom Glen, Rydal Road, Hampton, NSW 2790, Australia

The issue being discussed in this Forum is whether or not nations should live within their own biocapacity, an issue which has sometimes wrongly been interpreted as an attack on trade.[1] What is in question is unbalanced trade, where rich nations import far more ecological products and services than they export. In other words, rich nations spread their EF over poor nations to a greater degree than poor nations are able to extend their EF over rich nations.

An example of this is sale of fish from South America into the US. Fish that is exported from South America is not consumed by locals and therefore does not form part of the local footprint. Instead, it is consumed in the US and forms part of the US fish footprint. By this process part of the US fish consumption footprint extends to South America. Because South American nations are poor it is unlikely that they are able to purchase equivalent food from the US, ie they are unable to extend their EF over the US to the degree that the US extends its EF over them.

The situation is sometimes described in terms such as “the wealthy quarter of humanity consumes three quarters of the earth’s product,” and is generally regarded as immoral. This Forum casts the problem in terms of nation states.

As is mentioned elsewhere in this Forum some nations have almost no biocapacity and are not likely to live within it. The wealthy city-state of Singapore, for example, would need to reduce her population by a factor of about 10,000 to live within her biocapacity. She would cease to be a modern city and transport hub. Since no large city lives within its biocapacity, and all rely on other regions to supply produce and accept waste, Singapore may argue that she is the same as all other cities. The only difference is that the area that supplies her, on which her EF falls, is not under her sovereignty.

The ecological imbalance of trade between nations is generally obscured by the practice of expressing trade figures in monetary terms. Many aspects of international finance have the effect of ensuring that poor nations export much of the product of their biocapacity, thus enlarging the EF of the wealthy nations. Moreover, the very success that poor nations have had in expanding their production, which they have been encouraged to do so they can repay their international debt, has had the unintended effect of depressing the prices they can obtain for their goods. Thus they get only a small reward for their exports, and as a result they have little opportunity to expand their own footprint.

The situation has been well expressed:

> . . . our own population survive only by appropriating a significant part of the resources of these poor countries — most shamefully through international debt.[2]

> . . . in developing countries, farmers who once could at least feed their families and local communities now go hungry while they grow plantation crops for export (often at the behest of a government beholden to the International Monetary Fund or the World Bank.[3]

Attempts are made to justify the situation by describing poor nations as ‘developing’ nations with the implication that if they play the capitalist game they will become wealthy, ie they will have a large per capita EF. Unfortunately researchers such as Pimentel and Wackernagel make clear the planet cannot provide a large per capita EF for six billion people.

It appears difficult to offer any moral justification for wealthy individuals and nations maintaining their comfort at the expense of others. However the ethics of the situation may be irrelevant since the wealthy show no sign of abandoning their standard of living. They will of course lose it anyway as energy supplies falter. The only solution appears to be a drop in global population to a level where the planet can offer an acceptable EF to all.

1. Discussed, for instance, in Ian Moffat, "Ecological footprints and sustainable development" *Ecological Economics* 32,(2000), p.360.
2. "OPT Position Statement," *The Pherologist*, vol.5, no. 3, August 2002, p.4.
3. Peter Austin, "Caught in Trade Web," *The Land*, 16 January 2003, p.7. _

William Stanton's contribution to the forum is some pages further ahead (p. 14). There happens to be space available here to mention his recently published book, *The Rapid Growth of Human Populations 1750-2000: Histories, Consequences, Issues, Nation by Nation*.[1] The book will be reviewed in a future edition of this journal. Let me, in the meantime, offer a few thoughts.

David Willey and I thought that, if everyone could be persuaded to read Clive Ponting's *A Green History of the Earth*, OPT's work would be done. We agreed with the comment of a reviewer writing in the *Observer*, quoted on the front page of the Penguin edition: "If there is a single book on the subject to engage the enthusiast, silence the cynic and enlighten the ignoramus, this is it." Thus there can hardly be higher praise than to say that Ponting's book and Stanton's bear comparison. The following two paragraphs, taken from the back cover, give some idea of the remarkable scholarship that has gone into the book, and the format that has been adopted:

> Running through the book on the *upper parts* of the pages is new reference material: an assemblage of 235 graphs and tables showing, in detail, the recorded growth of population in each of the world's independent nations, as well as in 49 geographical regions which have, separately, useful and relevant records. Each graph is accompanied by a brief historical summary of political, cultural, ethnic and environmental change. The graphs appear in alphabetical order in four groups based on current population size, as indicated on the edge of each right-hand page.
>
> Running through the book on the *lower* parts of the pages is the Commentary, which discusses how and why the evidence of the graphs amplifies or is at variance with conventional wisdom and political correctness, and goes on to outline scenarios of population development based on the new evidence.

[1] Multi-Science Publishing Company Ltd. ISBN 0 906522 21 8. Published September 2003. 230 pp. £25.

When I was sending out invitations to contribute to the *2nd Footprint forum, Part II,* Jim Duguid was still engaged in finishing off his admirable eighty page booklet, *Population, Resources, and the Quality of Life*,[1] so I did not extend the invitation to him, despite his lively interest in eco-footprinting. However, when Jim sent me a copy of a letter that he had written to Edmund Davey, which contained a small selection of the 200 letters he has had published in the *The Scotsman* and *The Times* during the last 15 years, it was clear that he had — in a paragraph addressed to Edmund and in a letter to the *The Scotsman* — already given an elegant answer to the question that is to be addressed in this *2nd Footprint forum, Part II*. With Jim's permission, I have extracted text from two letters, to make what I think is a valuable contribution to the forum.

For those who do not know Jim, it will be of interest to learn that he is Professor Emeritus of Medical Microbiology, University of Dundee and, as will be evident from the words below, he is still in top form at the age of 83.

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From J. P. Duguid, Oaklands, Merlewood Road, Inverness, IV2 4 NL, Scotland.

Biology and population dynamics. The difficulty of persuading most otherwise concerned adults is that few of them have received sufficient education in biology to teach them about population dynamics and the harsh realities of natural life on which the superstructure of our sophisticated modern civilization has been erected. Many well-intentioned adults have already developed a mind-set based on the biologically impossible view that "if everyone cared enough and shared enough, everyone would have enough," and many attribute all human ills to the greed of other people, not nature. Adults with those entrenched attitudes are almost impossible to persuade to entertain new ideas, just as old dogs can't learn new tricks. [letter to Edmund, 29 December 2002]

Those who promote the entry of asylum and welfare seekers should note it is not just their own resources they will give away, but those of their fellow-countrymen and their children.

The ethical principle proposed by the Optimum Population Trust is that each nation should live within the limits of its own ecological resources. Yet, Britain is so densely populated that, by its imports of food and commodities, and disposal of pollutants, it appropriates the resources of an amount of land over three times larger than itself. For equity, its population should be reduced from 60 to 20 million.

The problem is not one that hospitality to a few can bring to a happy end. About half mankind lives in poverty or under oppressive government, 800 million being badly malnourished. If 'rich' countries like Britain permitted free entry, they would be overwhelmed by the continuing inflow of migrants. That flow would go on until the conditions of life in the receiving country had been made so bad by overcrowding, environmental damage, the struggle for amenity, and breakdown of civil order, as to deter further entrants.

Our moral aim should be to help people live a better life in their own land.

[*The Scotsman*, 1 January 2001]

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[1] James P Duguid's (CBE, MD, BSc FRCPath) booklet was published in 2002 by Population Policy Press, Llantrisant, Pontyclun, CF72 8LQ, UK <info@popolpress.com> (£5 incl. p&p). It is a digest of information and interpretations from publications of the Optimum Population Trust UK, and others.

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From John Guillebaud, Co-Chair of OPT, UK. info@optimumpopulation.org

The essence of the question that we are asked to address is this: should each nation be responsible for living within its own biocapacity, or should the people of the world jointly share the responsibility of ensuring that the whole world remains within the world's biocapacity. I would suggest that we do not need to dig deep to see that the second idea is not going to work. Let us look at some relevant figures.

Of the seven nations shown in Table 1, the only one which is not overpopulated is Zaire (The Democratic Republic of Congo). It alone has a large amount of fertile land in relation to its population. All the others have vastly overshot their carrying capacity, where carrying capacity is to be understood as the ability of the national land to supply the population with adequate food, fibres, and energy (this allows, of course, that balanced trade in ecological goods does not infringe that basic concept).

While eco-footprinting assesses carrying capacity in terms of food, fibres, and energy land, we should not overlook another limit on carrying capacity, namely water supply. The populations of Rwanda and Algeria have already exceeded their supply of renewable water. The generally accepted benchmark for water scarcity is 1000 cubic metres per person. In 2000, Rwanda had 815 m^3/person and Algeria 454 m^3/person.[1]

So have the governments of these nations had the foresight to control population growth? The changes in the doubling times are shown in Table 1. The first such column is based on the mean population growth rate between 1950 and 2002; the second one is based on the population growth rate in 2002. Clearly there has been little abatement of growth. How can we expect world agreement in such a situation? The corollary is that national governments need to take responsibility for reducing their own population to a level that does not overshoot the national biocapacity. Moreover our government, in the UK, *should* be giving a lead.

[1] *People in the Balance*, R. Engelman, R.P. Cincotta, B. Dye, T. Gardner-Outlaw, J. Wisnewski. 2000. Population Action International, Washington, DC 20036, USA. 32 pp.

Table 1: Changes in the rate of population growth of selected nations for the period 1950-2002, compared to the year 2002.

Population changes, 1950 to 2002				During 2002 only		
Notes	(a)	(a, b & c)		(b & c)		(b)
Year(s)	1950	1950-2002		2002	2002	2002
	Population million	Average annual change %	Doubling time years	Population growth %	Doubling time years	Population million
Haiti	3.3	1.5%	47	1.7%	41	7.1
Afghanistan	9	2.2%	32	2.4%	29	27.8
El Salvador	2	2.3%	30	2.3%	30	6.6
Rwanda	2.1	2.5%	29	2.2%	32	7.4
Algeria	8.8	2.5%	28	1.8%	39	31.4
Ethiopia	18.4	2.5%	28	2.5%	28	67.7
Zaire (Congo)	12.2	2.9%	24	3.1%	23	55.2

Notes: (a) Data from *Wild Earth,* page 4 of Fall 2002 issue.

(b) Data from the "2002 World Population Data Sheet" of the Population Reference Bureau.

(c) Doubling times are calculated by dividing the percentage growth rate into 70. They are merely a graphic way of appreciating growth rates. The past is fact, but needless to say no one can predict, with any certainty, whether growth rates will change after 2002.

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From David Pimentel, College of Agriculture and Life Sciences, and Marcia Pimentel,
Division of Nutritional Sciences. Cornell University, Ithaca, NY 14853, U.S.A.

The concept of the ecological footprint has demonstrated its usefulness in identifying the impact of a given population on the resources of a given country. Its application can assist decision makers and the public to understand how the numbers of people relate to the available resources. The paper, *An Optimum Population for North and Latin America* (Pimentel et al., 1998), placed on record our credentials as committed supporters of the proposition that nations should live within their biocapacity. So our contribution to Part II of this forum focuses on showing the magnitude of the global challenge, and hence the urgency of taking appropriate action.

As the Earth's population expands, it intrudes over the landscape farther than ever before, with houses, roads, industries, and countless human activities. In this process, prime cropland, freshwater, and other resources vital for food production are being compromised.

More than 99.7% of human food comes from the land, and less than 0.3% from oceans and other aquatic ecosystems (FAO, 1998). To sustain adequate food production, sunlight, fertile cropland, and fresh water are required. Successful agriculture also depends on substantial inputs of both renewable and finite fossil energy for cultivation, fertilizers, pesticides, and irrigation.

During the last two decades, when food production should be increasing to balance the needs of an expanding population, world cropland per capita declined 20% (Brown, 1997). Yearly, more than 10 million hectares of cropland are degraded and destroyed because of wind and water erosion (Pimentel et al., 1995). Erosion is intensifying worldwide, especially in developing countries where the rural poor remove crop residues for cooking fuel, and valued forests are being removed to provide new cropland and fuel. Together these encourage soil erosion.

Increased human numbers require more freshwater for irrigated agriculture as well as for personal use. Worldwide, freshwater sources from rivers and aquifers are already being stressed and water shortages emerging.

Changes in the food supply have become apparent. For example, food availability per capita, as measured by cereals, has been declining since 1994 (FAO 1961-1999). Cereals are the mainstay of human diets, comprising 80% to 90% of the world food supply (Pimentel et al., 1999). Although cereal grain harvests per hectare have increased slightly since 1984, these harvests are being divided among ever more people, decreasing the per capita food availability

Meanwhile, the world population is projected to increase from its current level of 6.2 billion to 12 billion within 50 years, based on its current rate of growth (PRB, 2001). Even if a policy of 2 children per couple were adopted tomorrow instead of the current 2.9 children, the world population would continue its increase for approximately 70 years before eventually stabilizing at nearly 12 billion (Pimentel et al., 1999). The vital factor affecting population growth is 'population momentum', which stems from the current young age structure (Bartlett, 1997-1998). Thus the greatest problem in achieving 'population turnabout' lies with those nations which, in past decades, have been experiencing the most rapid growth.

Signaling the impact of the human population explosion is the recent World Health Organization report that indicates more than 3.5 billion people now are malnourished (WHO, 2000). This is the largest number and proportion of malnourished (calories, protein, vitamins, iron, and iodine) ever in history. Malnourishment diminishes productivity and increases the human susceptibility to serious diseases, like malaria, diarrhea, and AIDS.

Granted no one can predict exactly how large the human population will be in fifty years. But we know the basic resources of the earth that support human life are declining; some finite resources will be depleted and future food security is in jeopardy.

Either we have the foresight and are brave enough to limit our numbers, or nature will impose its limits on our existence.

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I was asked to expatiate on the above assertion that, "the world population is projected to increase from its current level of 6.2 billion to 12 billion within 50 years, based on its current rate of growth." First, one needs to be clear that projections are not forecasts. Demographers often give three projections, a low one, a high one, and something in between. When they hint at which one is the most likely, events usually prove them wrong! This is hardly surprising, given the number of unpredictable variables, such as disease and starvation. What one can say is that the above *projection* is correct, based on data from the Population Reference Bureau *Data Sheet 2002*: since world population in mid 2002 was estimated as 6.217 bn, with the then current rate of increase of 1.3%, the population in 2050 may be *projected* as $6.217 \times 1.013^{48} = 12$ bn**.** OPT thinks 12 billion is highly improbable, as do many others, including Edward Goldsmith, founder editor of *The Ecologist*, and David Pimentel himself, as is evident from a paper in which he was lead author: "Ecology of Increasing Disease: Population growth and environmental degradation." *BioScience*, Vol. 48. No. 10: 817-826, 1998.

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From J. Kenneth Smail. Department of Anthropology, Kenyon College, Gambier, Ohio, 43022. USA.

Although the following observations are common knowledge, they are likely to characterize the lives of our immediate (21st century) descendants and are thus pertinent to the question posed for the *2nd Footprint forum*, *Part II: Ethics of Carrying Capacity*.

1. Because human nature itself is unlikely to change, one can expect that humans, both as individuals and as groups, will continue to exhibit deeply-rooted (evolved?) propensities toward excess procreation, a narrow focus on the near-term and familiar, and a generalized distrust of the unfamiliar.
2. The political dominance of the nation-state will undoubtedly continue, with any tendency toward larger supra-national structures (regional clustering) likely to be counterbalanced by political fragmentation, particularly in areas of the world where access to essential resources becomes increasingly problematic.
3. Efforts to increase per capita consumption levels, regrettably coupled with an economic mindset focused on seemingly limitless and unsustainable growth, seem likely to persist for several more decades, as nations in both the developing and developed worlds attempt to achieve and/or maintain a ‘moderately comfortable’ standard of living.
4. The era of inexpensive energy, particularly that based on non-renewable petroleum resources, will almost certainly come to an end by mid-century, and it remains a moot point whether suitable (and sufficient) substitutes can be developed.
5. Ongoing scientific investigations, on a variety of fronts, will ever more clearly demonstrate: (a) that the Earth does indeed have finite physical and biological limits; (b) that these limits are increasingly quantifiable (by techniques such as eco-footprinting and other methodologies); and (c) that these limits may already have been surpassed in numerous ways.
6. A fully effective program of wilderness preservation and biodiversity conservation will likely require that some 15% to 20% (or more) of the Earth’s land and water surface be permanently set aside (and discreetly managed) to ensure the survival of the other 99.9% of organic nature.

While these observations are hardly exhaustive, they are at least sufficient to represent what I have articulated in several essays over the past decade, specifically the need for a very significant reduction in global human numbers, probably on the order of 75% or more, from a mid-to-late 21st century peak of 9 to 10 billion to a future (23rd century and beyond) sustainable optimum in the 2 to 3 billion range. If one argues that humanity’s fundamental goal — indeed, ethical first principle — must necessarily be to preserve the stability and resilience of the Earth’s integrated ecosystems, it seems increasingly obvious if not irrefutable that only a global population ‘optimized’ at a considerably reduced size will provide the opportunity to build a better, more equitable, and fully sustainable quality of life for everyone. Notwithstanding the great disparity in current definitions of the nation-state (e.g., from Singapore to Canada), and given the limited time available for effective remedial action, it is difficult to imagine any ethical stance (workable rule) other than that the ‘political entities’ of the near and more distant future must quickly begin to take responsibility for constraining their population(s) and lifestyle(s) so as to live well within the limits of their respective biocapacities.

CONTRIBUTION TO A 2ND FOOTPRINT FORUM, PART II

From William Stanton, of OPT. Kites Croft, Westbury-sub-Mendip, Wells, Somerset. BA5 IHU

Eco-footprinting is one of several methods used to assess carrying capacity. It has a built-in ethical dimension, because if a nation's footprint exceeds its ecological capacity it is perceived to be at the expense of other nations. That perception is logically sound, insofar as Earth's biocapacity is finite, and if some nations use more of it than they possess, less is left for the rest.

The question we are asked to address is: should nations live within their biocapacity? The concept is morally persuasive, but difficult to address, because the goalposts shift. For example, national biocapacities have vastly expanded since about 1750, when industrial agriculture was born. They will contract when petroleum, which fuels modern farming, becomes scarce and expensive. Also, the egalitarianism involved would tend to enfeeble small European nations like Britain compared to larger nations whose sole claim to greatness would be their size and fertility (e.g. the Democratic Republic of Congo). Intellect and innovation, which distinguish the human species, would be devalued. For the past several years I have been researching the demographic histories of nations (e.g. England in *Better World*, no 3, 1994). One fact emerges with great clarity: when physical restraints on growth collapse, populations tend to explode. This situation has been so common, since the Industrial Revolution introduced ways to end chronic malnutrition (by increasing biocapacity), that I use the acronym WROG (Weak Restraints On Growth) to define the period.

The world has enjoyed 250 years of WROG, thanks to cheap energy from fossil fuels, especially oil, but if oil geologist Colin Campbell,[*] is right, as I believe, the WROG period will end for most nations within a few decades.

Thus although a moral principle linking population to biocapacity would seem to be desirable, few nations will be motivated to change their lifestyles until the end of the WROG period is imminent. If they do change, it will not be for moral reasons, but to facilitate their survival in the post-WROG world of strong restraints.

Ferguson asks us to consider some concrete examples. Example (b) exists today in nations like Singapore or Monaco, which have virtually no biocapacity. Like the Netherlands, their intellectual prowess enables them to buy other nations' surplus biocapacity. While surpluses exist, the trade is perfectly ethical. No-one can decree that Singapore must close down.

Nevertheless, a general principle that nations should not usurp other nations' biocapacities is an appropriate ideal. Whether politicians espouse that ideal, or whether they profess to believe in equal sharing among nations, below the surface layer of political correctness they are solidly Darwinian, promoting the well-being of their own nations (and thereby themselves). The citizens who elect them are not very different, but there is a glimmer of hope for preserving areas of the world where the better aspects of civilization can continue to flourish.

In Europe and the USA, politicians flout the wishes of their electors with respect to immigration. People in general would like only *balanced* migration, i.e. no excess of incomers over outgoers. The big challenge for Europe and the U.S., regions where democracy supposedly prevails, is to hold our politicians to account on this. Europe already has a declining indigenous population, so balanced migration would move us strongly in the right direction both to reduce the European eco-footprint and to prepare for post WROG survival.

[*] Campbell, C.J. 1997. *The Coming Oil Crisis*, Multi-Science Publishing Company. 210 pp.

AN OVERVIEW OF THE 2ND FOOTPRINT FORUM, PART II

by Andrew Ferguson

On page 29 of the April 2003 issue of this journal I said, "I see *Part II* of the forum being similar to *Part I*, insofar as the truth of the matter is perfectly obvious, but it still requires an overwhelmingly clear exposition of the situation in order to get people to change their preferred way of looking at things." The seven contributions above, all lean in the same direction, and perhaps I need to reassure readers that I did try to extract responses from people who were likely to espouse a different view from those published above. The following four paragraphs are taken from an email circulated in January of this year to participants in the forum.

* * * * *

Since all contributions received so far have been *supporting* the ethic that nations should live within their biocapacity — which is what might be termed the 'realist' viewpoint — it is appropriate for me to emphasize that I have also given invitations to those who appeared to espouse the alternative approach, which might perhaps be designated the 'universalist' viewpoint.

In the introduction, I drew attention to the views of van Vuuren and Smeets, who apparently think that the idea of nations living within their biocapacity is not 'mainstream thinking'. They do not divulge what they deem 'mainstream thinking' to be, but I suspect it is the 'universalist' view. Mathis Wackernagel, as we have already noted, appears to like to keep one foot firmly planted in the camp of the 'realists' and the other in the camp of the 'universalists'! Two people who appear to be in the 'universalist' camp are Jeroen van den Bergh and Harmen Verbruggen, for in the Tenth Anniversary Invited Paper for *Ecological Economics*, (29 (1999) 61-72), pertaining to eco-footprinting, it seemed they were endorsing something along the line of thought of van Vuuren and Smeets when they said:

> In our view, trade can in principle spatially distribute the environmental burden among the least sensitive natural systems. Since it is not realistic to expect the historically developed spatial distribution of human societies to change significantly over a short period of time, and because natural resources are immobile, a spatial matching of consumption, production and resource use is only feasible on the basis of trade of commodities and resources.

Through the dense academese, I think it is possible to discern a 'universalist' view, entailing that (a) it is OK for some nations, e.g. the UK and the Netherlands, to appropriate the biocapacity of other nations, and (b) that there is no particular limit to the extent to which this is permissible, nor to the time over which it might be allowed to continue.

In their book, *Sharing Nature's Interest*, the authors, Nicky Chambers, Craig Simmons and Mathis Wackernagel, did not divulge whether they were 'realists' or 'universalists'. Perhaps Chambers and Simmons share Wackernagel's disposition for straddling the two positions! In one chapter of their book, 20 questions were given which the authors said were the questions most frequently asked about ecological footprints. However, they studiously avoided the question which is the subject of this *Part II* of the forum! I hope I have now established my credentials for not preselecting 'realists'. With those few words of encouragement (perhaps spiced with an element of provocation) to those who wish to defend their different view, here are the three latest contributions, which I hope will be helpful to other prospective contributors.

* * * * *

The success of the provocation was limited, and in May of this year I tried to find out the general opinion of most people. The question I put to those who had not already responded was as follows:

> Question: Does the world need a general ethical principle which prescribes that each nation should either be living within the limits of its own biocapacity (i.e. Footprint equal to or less than biocapacity), or at least moving in that direction? (The only obvious alternative principle is that the whole world should bear a joint responsibility for living within the biocapacity of the whole world.)

Multiple choice answers:

a) Yes.
b) No.
c) The answer to the question is too complicated to answer simply yes or no.

There is a fourth broad category, let us say (d), needing subdivisions thus:

d i) The respondent wishes to espouse a view which is impossible to defend logically, so silence is the wisest policy!
d ii) The respondent is so dubious about the validity of eco-footprinting concepts, and the accuracy which can be achieved, that it can serve no useful purpose to discuss the related ethics.
d iii) This particular branch of ethics can be nothing but idle speculation, because nations will simply continue to do what is in their best short-term interest: ethics in this sphere belong to cloud-cuckoo-land.

I could have offered this ‘d’ category at the outset, but I felt (and later had evidence to prove it) that some respondents would be too circumspect to classify their own positions accurately! Nevertheless, later I did offer it to those who had conveyed some of their thinking to me. So who fell into which category?

(a) The ‘contributors’ in the preceding pages have spoken for themselves. I think we can agree that they all belong to category ‘a’, although with varying degrees of affinity to ‘d iii’. William Stanton, whose amazingly erudite book, *The Rapid Growth of Human Populations 1750-2000: Histories, Consequences, Issues, Nation by Nation*, has just been published, certainly has a powerful undercurrent of ‘d iii’ in his thinking.

As to the rest, Robert Herendeen put himself in the ‘a’ category. Virginia Abernethy explained her position as 90% ‘d iii’ with only the remaining 10% allocated to the ‘a’ category!

Val Stevens said that although ‘d iii’ was closest to her belief, she had to reject it in favour of ‘a’ for two reasons: first, ‘d iii’ appeared to be an escape from, rather than an answer to the question posed by this Part II of the forum; second, ‘d iii’ would constitute resignation into accepting our fate rather than trying to influence it, and that is something to which it is hard to reconcile one’s conscience. This, incidentally, is also my position.

(b) Detlef van Vuuren wrote to apologize for having found it difficult to make time to compose a complete reply, but indicated that his position was “very close” to ‘b’.

Indeed it seemed that his views had not changed from those expressed in the quotation in the introduction (p. 3).

He stated, in his reply, that, “The test whether a country (with often arbitrary boundaries) is within its own carrying capacity does — in my view — not pass a test of having enough evidence to support it.” So perhaps we may deduce there is an element of ‘d ii’ in his thinking.

I tried to teasel out of him a response to the specific question raised in the introduction, about an ethical rule to address the problems outlined by the scenarios for the Netherlands and China (p. 4). His response indicated that he would find that task of immense difficulty, indeed comparable in magnitude to the insurmountable difficulties faced in *Part I* of the forum by those who wished to defend the ‘carbon absorption paradigm’!

(c) Putting himself specifically into category ‘c’ was Paul Ehrlich. William Rees said that he was “inclined to answer ‘c’ for pragmatic and empirical reasons.” These pragmatic and empirical reasons amounted to ‘d iii’.

(d) Edward Goldsmith rang me to confirm what I had generally understood from his previous comments, namely that he belonged to the ‘d iii’ category. Putting themselves, by default, into the broad category ‘d’ were: Nicky Chambers, Robert Costanza, Rod Simpson, Manfred Lenzen, Kevin Macdonald, Jeroen van den Bergh, Mathis Wackernagel.

Jim Duguid did a good job of laying out, on page 9, the psychological background which explains why it need be no surprise to find that out of the seventeen people invited to join the forum, about half fell into the ‘d’ category.

In the introduction, it was stated: “The least that might emerge from this forum is to find out if *anyone* can propose an ethical basis for using Ecological Footprints, which is politically realistic, other than that nations should live within their biocapacity.” Perhaps “anyone” was an overstatement, because there may of course be some ‘Einstein’ out there who should have been consulted, but it is clear that no one whose views were canvassed for this forum was able to put forward such a proposal.

Acknowledgements

Rosamund McDougall was of great assistance in disseminating, by email, the contributions to the forum as they came in. I am also grateful to the several people who engaged in correspondence on the matter under discussion, even though their efforts did not mature into a publishable contribution.

> As a doctor, I am ashamed about the lack of effective action, when it is so screamingly obvious that our excellent medical efforts in *death control* over the past 150 years have to be balanced by adequate voluntary *birth control*. This is all the more ridiculous when massive national surveys now show that family planning is

wanted by most of the world's women, yet their needs are not met. Population is not now a problem needing a solution: it is a solution needing proper funding.

John Guillebaud (OPT Co-chair) in *Better World, Issue No. 3, January 1994.*

In the ensuing dialogue, Secretary of the Optimum Population Trust (UK), Edmund Davey, takes the role of the 'Plain Man', asking questions of interest to himself and other members of OPT.

A PLAIN MAN'S QUESTIONS CONCERNING TIME-INDEPENDENT, RENEWABLE ENERGY BACK-UP

Asked by Edmund Davey; answers provided by Andrew Ferguson

Edmund Your update on *Wind/biomass energy capture* (OPTJ 3/1) was interesting, but I could not help wondering whether different assumptions could have been made, thus arriving at a better outcome.

Andrew I would be interested to hear your proposals.

Edmund It seems to me that the need for biomass, to supply 'back-up' power, could be reduced if the 'back-up' came from a large grid, instead of it all coming from biomass. I appreciate that 'back-up' is perhaps not an ideal word: wind turbines really need to be thought of as part of a composite system operating in combination with one or more other energy sources, but 'back-up' will do as a short-hand description.

Andrew The main effect of a large grid would be to share the problem more widely. Also you must remember that we are considering the situation of having to rely on renewable energy alone, and the only fairly time-independent renewable energy source, apart from biomass, is hydropower. We have already exploited most of the available hydropower, except in a few special places like Iceland, and hydropower supplies only a small part of total electricity. For instance, in the U.S., hydropower supplies about 8% of the total electricity.[1] Thus although one could have a back-up system composed of a grid fed by hydropower and biomass, the composite energy capture of a hydropower and biomass system would not be significantly higher than biomass alone, because of the small part that hydropower would play.

That is really an adequate explanation in itself, but as a matter of interest, let us look at the energy capture of hydropower. Pimentel gave some figures based on a random sample of 50 U.S. hydropower reservoirs, ranging in area from 482 ha to 763,000 ha (P&P, p. 206). The average land used to produce a billion kWh/yr was 75,000 hectares. In primary energy terms that works out at an energy capture of 4.6 kW/ha; moreover that is a gross figure rather than a net one. Anyhow, using hydropower, at 4.6 kW/ha, to satisfy a small proportion of the total requirement is not going to make much difference to the 2 kW/ha which is available from biomass. Moreover it could very well be argued that hydropower needs a back-up system itself, since when the reservoirs are low there is little power available. Hydropower is not a back-up system. It can rarely be used to fill up the peaks in demand, or substitute for diminished supply from other sources.

Edmund I see the problem. Can you remind me why biomass gives only 2 kW/ha.

Andrew A sustainable yield of biomass is probably 3 dry t/ha/yr, which is about 6 m^3 of wood per year. At 20 GJ/t that is 60 GJ/ha/yr = 60 / 31.5 = $\underline{\underline{2}}$ kW/ha. Again one should bear in mind that is not a net figure. As Jill Curnow has pointed out, collecting biomass without the benefit of liquid fuels is a daunting task.

Edmund Yes, that is something people tend to forget. How about another possibility, namely converting some of the electricity into hydrogen, and then regenerating the electricity when needed.

Andrew The trouble with that is two-fold. The first point — something that is really adequate in itself — is that wind power is limited: there is only so much available. So there is none to spare to make hydrogen. The second point is that even if there were sufficient electricity available from the wind turbines, two further steps are needed: (a) the process of electrolysis, which is about 70% efficient, and (b) the process of transforming the hydrogen back into electricity. Trainer, 1995, p. 1016, gave 40% for the fuel cell and 92% for AC conversion. Moreover the AC of the wind turbines would need to be converted to DC for the electrolytic process, and then converted back to AC after transformation by the fuel cell. However, I am told the electrical current conversion processes have become much more efficient, and fuel cells have improved, so let us make the optimistic assumption that AC/DC, fuel cell, and DC/AC transformations can be achieved with an overall efficiency of 60% efficiency. Then the whole conversion chain would be achieved with an efficiency of 0.70 x 0.60 = 42%. That means that the cost of electricity would be 1 / 0.42 = 2.4 times as expensive as it would be when the electricity can be used directly, *even before* taking account of: (a) conversion to DC and the equipment needed for electrolysis, (b) costs of hydrogen storage, (c) the currently very expensive fuel cells, and (d) the inverters to produce AC current at the right voltage.

Edmund OK that's as dead as a dodo, how about using the wind turbines to pump water up to a high level, which could be used to regenerate the electricity when needed.

Andrew You are an inveterate optimist! I will have to remind you that there is not the electricity to spare in the first place, but even were it to be, Ted Trainer (1995) says that only 65-70% of the energy initially available can be retrieved from the stored water, and volumes are a problem too: to store the energy equivalent to the output of a 1000 MW generator, over 16 hours, would require low and high dams each of approximately 120 million cubic metres (assuming a 50 m head).

Edmund OK, storing wind energy belongs to cloud-cuckoo-land. One other possibility is solar ponds or the solar columns that the Australians are experimenting with.

Andrew It is true that both these systems have a heat storage capacity, but very high insolation is needed to make them viable. Trainer (1995) quotes studies in the Dead Sea area, where during some months insolation is at 350 W/m^2. Over the year, the electricity delivered amounted to 2% of the insolation. It seems unlikely that, in most parts of the world where power is wanted, these systems will make a large contribution to the whole. The world should watch the experiment in Australia with interest, but we cannot expect it to work in Europe or most of America.

Edmund I know that we have excluded the possibility of photovoltaics making a contribution, but solar troughs are yet another possibility. Even though they are not time-independent, perhaps they could help to fill in some of the back-up requirement.

Andrew Solar troughs need themselves to be considered as a composite system, since they only supply power when they receive the benefit of the sun. So along with wind turbines, they need to be considered as a composite system if they are to be able to deliver power when needed. Making them into a composite system by using biomass as their back-up, would, on account of the low energy/land ratio of biomass, dramatically lower the composite energy/land ratio of the system. So the overall effect of solar troughs on providing back-up to wind turbines will be small.

Edmund It looks a grim picture. Let me make a last bid for a ray of sunshine. It relates to that 14% loss you mentioned, associated with the four and a half hour warning period required in the UK. That may be far less of a problem in the U.S., where it is easier to predict the weather.

Andrew Well done Edmund, you have found a ray of sunshine but I have to say it does not shine too brightly. For I must point out that the losses associated with that short term variation of wind were only the smaller part of the reason for needing to consider wind power as part of a composite system. The main problem is the long term variation which causes them to have a capacity factor of around 22% in northern Europe, and probably only a bit higher in the UK (there is a lack of detail in the UK data).

Edmund I feel sure that this is a naive question, but in your *Update* paper on *Wind/biomass Energy Capture* (OPTJ 3/1, April 2003, p. 6), you considered only 100 MW_e rated capacity. Surely if you considered a larger figure, say, 12,000 MW_e, then wind could take care of a significant proportion of electrical demand.

Andrew The essential point is the ratio between the electricity which can be supplied by wind turbines and that which must come from a time-independent back-up system. If the back-up system can be provided by coal, then the only bar to providing a significant proportion of electricity by wind turbines is the additional cost of the dual system, and the problem of finding acceptable sites. However, if we have to rely on biomass for back-up, there is a problem of land availability. We saw on page 8 of the *Update* paper, that building a composite system to supply 22% of the UK's electricity by wind and biomass would require about 7 million hectares, which is clearly not available.

Edmund I now see the whole picture perfectly clearly. Biomass has to be the main back-up to provide time-independent power, and since there is limited spare ecological capacity to grow biomass, the only answer is to dramatically reduce population before fossil fuels become scarce.

Andrew You are absolutely right Edmund. I greatly admire your ability to form judgements on the basis of the evidence alone!

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Endnote

1. The primary energy equivalent of the hydropower delivered in the U.S. is 3 quads = $3 \times 1.055 \times 10^{18} = 3.165 \times 10^{18}$ J.

   U.S. electricity consumption in 2000 was about 3.5×10^{12} kWh_e/yr = $(3.5 \times 10^{12} / 0.33) \times 3.6 \times 10^{6}$ J = 38.2×10^{18} J.

   So hydropower supplies 3.165 / 38.2 = 8.3%

On page 9 of OPT 2/1, namely the April 2002 issue of the *OPT Journal*, I accused *World Watch, The Ecologist* and *New Scientist* of being determined to maintain a Panglossian view of a 'hydrogen future'. In that piece, I made it clear that there was a weak spot in my assertion, because there was little information available regarding the performance of fuel cells; in particular, the extent to which they might improve on the internal combustion engine when used in a vehicle. That has changed with data from various sources, starting with an article about the prototype *Ford Focus Fuel Cell Vehicle* in *The Times*, by Anthony Browne, 17 October 2002. Then came data on a *Honda FCX*, retrieved for me by David Pimentel, from <www.fueleconomy.gov>, 5 December 2002. Lastly, confirmation came from an article edited by Paul Hudson in *The Telegraph*, 18 January 2003, which provided two consumption figures.

As it is the oft-repeated implication of the 'experts' that hydrogen plus fuel cells is a combination which will answer all our future energy problems, a spotlight on the matter is needed. So as to maintain maximum transparency, and also to keep some of the detail out of the main text and to allow space to cover some other points of possible interest arising from these reports, a more comprehensive analysis of them is given in Appendix A. However, while there may be various matters that are of background interest about using hydrogen as an energy carrier to power motor vehicles, by far the most important question is this: where is the energy to come from to make the hydrogen? To fully consider that point, some text is repeated from an earlier piece, which was titled simply *Verdict on the Hydrogen Experiment* (it dealt with burning hydrogen in an internal combustion engine rather than converting it in a fuel cell).

I should warn the reader that spelling is 'mid-Atlantic'! I use the word 'gasoline' rather than 'petrol', yet 'litre' rather than 'liter'. I only hope this will not cause offence on both sides of the Atlantic!

VERDICT ON THE HYDROGEN EXPERIMENT: AN UPDATE

by Andrew Ferguson

ABSTRACT: When a car is powered by hydrogen burnt in an internal combustion engine, it takes 3 litres of liquid hydrogen to move the car over the distance that 1 litre of gasoline would take a similar car. Drawing on some recent figures relating to the performance of prototype cars, in which the hydrogen is transformed into electricity in a fuel cell, this paper shows that these prototype vehicles used 2.3 litres of liquid hydrogen to achieve the same result.

A fuel cell might lower the *overall* cost of using hydrogen as an energy carrier to drive a car (depending on how much more expensive than an internal combustion engine the fuel cell proves to be). However, this paper shows that cost is not the main question. In Iceland, where energy from hydroelectric and geothermal sources is easily available, it is clearly viable to manufacture the liquid hydrogen. For the rest of the world, the unanswered question is where the energy is to come from.

Looking at the overall energy transformation, it would take 9.14 kWh of electricity, = 32.9 MJ *of electricity*, to produce hydrogen with the same motive energy as 1 litre of gasoline (which has an energy density of about 33.5 MJ/litre). This almost equal requirement for energy is a viable proposition when renewable energy can be generated directly as electricity from renewable sources, as in Iceland, but generating the electricity from fossil fuels would call for the use of about 32.9 / 0.33 = 99.7 MJ of fossil fuel energy, about three times the energy in gasoline, and that would be prohibitive both in consumption of fossil fuels and emissions of carbon dioxide.

Readers of the November/December 2000 issue of World Watch may recall the glow of a volcanic flare on its cover, with the words, *The Hydrogen Experiment: Descendants of the*

Vikings Embark on a Bold New Quest to Transform the World's Energy Economy. But perhaps the significance of the following two nuggets of information did not fully register:

1) Iceland has been producing hydrogen since 1958: the plant "uses about 13 megawatts of power annually to produce about 2,000 tons of liquid hydrogen."
2) In Iceland, the cost of electricity is \$0.02 per kilowatt hour (kWh), due to the availability of geothermal and hydro power.

Allowing for the fact that hydrogen burns more efficiently than gasoline when hydrogen is burnt in an *internal combustion engine*, 3 litres of liquid hydrogen will take a car as far as 1 litre of gasoline.{T1} The greater efficiency of a fuel cell improves on that, and it takes only 2.3 litres of liquid hydrogen to achieve the same result (see Appendix A).

We can calculate the need for 9.1 kWh_e of electricity to produce 2.3 litres (160 gm) of liquid hydrogen (Appendix A); and that is the amount — when used in a fuel cell — of hydrogen needed to take a car as far as a litre of gasoline, i.e. it has the same 'motive energy'.

Paying \$0.02 per kWh for electricity, the dollar cost of *the direct energy* needed to produce the 2.3 litres of liquid hydrogen — equivalent to a litre of gasoline — would thus be 9.1 x \$0.02 = \$0.18. Note that when I say "equivalent to a litre of gasoline," I mean equivalent when used in a fuel cell, although to save space I will not add that qualification on every occasion. The \$0.18 does not cover the transportation or storage of the hydrogen, or the *non-energy* costs of electrolysis and liquefaction. As a ballpark figure, to cover these other aspects, we can perhaps assign \$0.05 for each litre of liquid hydrogen. Thus, in Iceland, hydrogen should be deliverable at a cost of about \$0.18 + (\$0.05 x 2.3) = \$0.29, for the 2.3 litres that are equivalent to a litre of gasoline; or \$1.10 for an amount equivalent to a U.S. gallon of gasoline.

That is all splendid news for Icelanders. In the United Kingdom, when the cost of oil was around \$32 a barrel (\$0.20 per litre), the retail cost of gasoline was about \$1.20 per litre, or \$4.54 per U.S. gallon, of which about 75% was tax. So, in Iceland, the cost of liquid hydrogen, calculated as being 29¢ per litre of gasoline equivalent, would compare well with the *real* cost of gasoline, 30¢ per litre. Indeed, the Icelandic government could, assuming that the Icelandic taxpayer is as tolerant as the British, add on a 300% tax!

According to an article in *The Times*, U.K. electricity prices in October 2002 were languishing near record lows at US\$28 per MWh. However, energy companies were in such dire straits that they were having to close down capacity. Apparently the cost of generating electricity, using a gas-fired plant, was \$28 per MWh, rising to \$62 per MWh using older oil-fired plants. If we take \$35 per MWh as a price at which the generators would not be suffering too badly, that would be 3.5¢ per kWh, raising the cost of liquid hydrogen by about 50% compared to the previous calculation.{T2}

However, outside Iceland, costs are only of background interest; what is more significant than cost is whether the electricity can be made available, and if so at what environmental cost.

Accounting for only the direct electrical energy used to produce the liquid hydrogen that would be needed to replace the gasoline currently being consumed, each person in the United

States (281 million people as of 2000) would require 15,600 kWh/yr of electrical energy (which projects to 1.25 times the total electricity used in the USA).{T3} Were you to suggest to Utility executives that they should be able to produce a significant proportion of this *extra* electricity, they would — especially in California — fall about laughing. We will be lucky, they would reply, to keep pace with our population growth, which in the US is over 1% a year. Moreover, since natural gas supplies are peaking, we won't be able to do that for long.

The coal 'option'

The reason that we cannot resort to producing hydrogen from methane (CH_4) is the imminent scarcity of natural gas.{T4} If there is to be a 'hydrogen future', then the energy needs to come from *renewable* resources. Yet the coal lobby is strong in America, so perhaps we should divert for a moment to think of using coal to produce the electricity needed. The calculations are in Appendix A. They show that using coal to generate electricity, in order to produce hydrogen by electrolysis, requires about three times as much energy as is contained in gasoline which has the same motive energy as the hydrogen produced. With coal having a higher carbon content than gasoline, the release of carbon dioxide would be considerably higher than three times as much.

While not germane to hydrogen production, another point to consider is the option of producing synthetic gasoline from coal, as was done in Nazi Germany and South Africa. According to the most recent data I have, the total carbon released from synthetic gasoline (including release during the conversion process) is 76% more than would be released from burning gasoline refined from oil.{T5} The existing overload of atmospheric carbon, the large amount of coal needed, and falling ratios of energy output to energy input for coal (more energy needed to get the coal out as coal gets more difficult to access) combine to make it unlikely that synthesizing gasoline will be adopted on a wide scale.

Renewables

A favorite daydream of greens is to produce hydrogen from wind turbines, so let us survey wind energy potential. The American Wind Energy Association estimates that it would be possible to install, onshore and offshore, turbines with 355,000 megawatts of rated capacity. That might appear to be equivalent to about 355 fairly large power stations, but it is less than half of that, since the capacity factor (amount of output compared to rated output) of wind turbines, in the US, is probably about 25%, whereas coal-fired power stations usually operate at around 60%. Moreover, installation of the, for example, 355,000 turbines each of 1 MW capacity, and the task of connecting them together, would be a substantial undertaking, costing about 355 billion dollars. Once achieved, the turbines would supply only about 22% of current U.S. *electrical* demand — enough to satisfy 20 years of U.S. population growth.{T6}

To summarize, it may be possible to overcome the disadvantages of hydrogen as an energy carrier (one is that its boiling point is -253°C), but producing it will only be possible for nations which have substantial resources of renewable energy. That excludes *everywhere* except Iceland.

Why has it been necessary to update the previous article in the April 2002 *OPT Journal*? The reason is because in that, it was only *suggested* that fuel cells would not change the picture significantly. I had no firm data to back that judgement. With facts on consumption using fuel cells in cars becoming available, it seemed necessary to close off another ‘solution’ espoused by pipe dreamers. Another thing I learnt from the article in the *Daily Telegraph* is that it takes about as much energy to pressurise hydrogen to the high pressures, about 10,000 pounds per square inch, that are needed to achieve a useful energy density, as it does to liquefy it.

Finding the energy to make the hydrogen is the crux of the hydrogen problem, but Appendix A does cover more ground than that. One reason is to assist people who get the chance to test prototypes to ask the right questions about hydrogen. Asking questions may be helpful to the Ford motor company, which, according to Browne, spent US$450 million in research and development, including $2.5 million on the prototype car. If other manufacturers have been spending similar sums, it would seem advisable for them to give further thought to where the energy is to come from.

Conclusion

The wider conclusion to draw from this study is the one which often emerges from these pages: there are no easy solutions to capturing the power of the sun in ‘real time’. The corollary is that the only path to a better future is to reduce human population to something like two billion — even that figure is in doubt, being about three times the number of humans alive when the fossil fuel age started, in 1750 AD.

Appendix A: background to the above analysis

While hydrogen consumption in a vehicle can be measured in terms of distance per kg, or litre (of liquid hydrogen), the figure has little meaning unless one can compare it to gasoline (petrol) consumption. The consumption implications becomes clear only when the amount of hydrogen is assessed in terms of how much hydrogen is needed to replace a litre of gasoline. Thus the first step is to have a benchmark for a conventional car of similar carrying capacity to the hydrogen prototypes. The general opinion appears to be that a conventional car of similar capacity to the prototypes would have a consumption of 14 km/litre (= 33 miles per US gallon or 40 miles per Imperial gallon). That is our benchmark.

Next we must review the fuel consumption figures of the four prototypes:

The *Ford Focus Fuel Cell Vehicle* reported on by Anthony Browne, in *The Times*, 17 October 2002, gave rather ill defined figures for consumption, saying only that the 4 kg of hydrogen it contained would take it “more than” 200 miles. To allow a margin of error, let us take this as meaning 220 miles (354 km).

If 354 km requires 4000 gms of hydrogen,

14 km would require 4000 x 14 / 354 = 158 gms.

A *Honda FCX* received a more precise appraisal at <www.fueleconomy.gov> (5 December 2002): 51 miles (82 km) per kg of hydrogen.

If 82 km requires 1000 gms of hydrogen,

14 km would require 1000 x 14 / 82 = 170 gms.

The *Hydrogen 3* car produced by GM, and reported in the *Daily Telegraph*, 18 January 2003, provided two sets of figures. The first indicated that 3.1 kg of hydrogen would take the car 170 miles (273.5 km).

If 273.5 km requires 3100 gms of hydrogen,

14 km would require 3100 x 14 / 273.5 = $\underline{\underline{159}}$ gms.

The other set suggested that 4.6 kg would take the car 250 miles (402.25 km).

If 402.25 km requires 4600 gms of hydrogen,

14 km would require 4600 x 14 / 402.25 = $\underline{\underline{160}}$ gms.

Choosing a round figure from those data suggests that 160 gms of hydrogen will provide the same motive power (when transformed in a fuel cell) as 1 litre of gasoline. The volume of 160 gms of liquid hydrogen is 2.29 litres.{T7} Thus in round terms we can say that, using a fuel cell, 2.3 litres of liquid hydrogen are required, to provide the same motive energy as 1 litre of gasoline. The amount of electrical energy needed to produce 2.3 litres is 9.1 kWh; and if the electricity had to be made by burning fossil fuel, then the energy required would be 27.6 kWh_{th}.{T8}

Pressure problems

Reports on cars powered by fuel cell using hydrogen nearly always report the weight of hydrogen consumed or in the tank, but it is the volume and pressure that present the largest problem. In its most dense form, that is in liquid form, hydrogen has a density of 0.070 kg/litre (McGraw-Hill, p. 338 of Vol.1, 8th edition), and we have seen that 2.3 litres of liquid hydrogen are needed to replace a litre of gasoline.

Hydrogen liquefies at -253°C, and its critical temperature is -240°C. Above the critical temperature a gas can no longer hold its liquid form, so the pressure rises as the temperature rises. If liquid hydrogen, fully filling the tank, is allowed to warm up to 50°C, the pressure increases to 930 atmospheres, thus a robust container is required.{T9} According to the *Daily Telegraph* article, edited by Paul Hudson, 18 January 2003, the *Hydrogen 3* car could operate either on (1) hydrogen pressurised at 10,000 psi (680 atmospheres) with a 'spun-carbon' tank, or (2) using liquid hydrogen. For the latter, it would appear, from the above, that the tank would have to be designed to cope (for special situations), with a a pressure of 930 atmospheres (though less if the tank is not fully filled).

The efficiency of the 'hydrogen - fuel cell' combination

Hydrogen has a heat content of 120 MJ/kg (McGraw-Hill, p. 338 of Vol.1, 8th edition), or 120 kJ/g, and we have calculated that 160 g of hydrogen has the same motive energy as 1 litre of gasoline (the figure is 210 g in an internal combustion engine).

So 160 g of hydrogen would have a heat content of 160 x 120,000 = $\underline{\underline{19.2}}$ MJ (1 MJ = 1 x 10^6 joules).

Gasoline has an energy density of around 33.5 MJ/litre. Thus when used in a fuel cell, 19.2 MJ of hydrogen has the same capacity to move a vehicle as 33.5 MJ of gasoline. So it is 33.5 / 19.2 = 1.745 as efficient (or 74.5% more efficient) than gasoline.

The foregoing analysis seems fairly cast iron. It would be interesting to know why manufacturers claim that the fuel cell is 90% efficient and a gasoline engine 30% (as stated in Browne's article), giving a ratio of 3.0, when the more relevant comparison is 1.745. Is there a confusion about the ability of a fuel cell to (a) produce electricity and (b) to produce mechanical energy?

The problem of finding the energy to produce the hydrogen

Now we have reached the crunch item! Where to find the energy? When driving a car powered by a fuel cell, about 2.3 times the volume of liquid hydrogen will be consumed as gasoline would be in a similar car. We have also noted that the energy used *at the point of consumption*, when converting hydrogen, is 1 / 1.745 = 57% of what would be needed using gasoline. However, looking at the overall energy transformation, it would take 2.284 x 4 [kWh/litre] (endnote 3) = 9.14 kWh of electricity = 9.14 x 3.6 x 10^6 = 32.9 MJ *of electricity* to produce hydrogen with the same motive energy as 1 litre of gasoline (which has an energy density of about 33.5 MJ/litre). This almost equal requirement for energy is a viable proposition when renewable energy can be generated as electricity directly from renewable sources, as in Iceland, but generating the electricity from fossil fuels would call for the use of about 32.9 / 0.33 = 99.7 MJ of fossil fuel energy, about three times the energy in gasoline, and that would be prohibitive both in consumption of fossil fuels and emissions of carbon dioxide.

{T?} endnotes for *Verdict on the Hydrogen Experiment: an Update*

{T1} For the full calculation see endnote 2, p. 11 of *OPT Journal* 2/1, April 2002.

{T2} At $35 per MWh, or 3.5¢ per kWh, compared to 2¢ per kWh, the *energy* cost would increase by a factor 3.50 / 2 = 1.75.

So the increase in cost would be $(0.18 x 1.75 + ($0.05 x 2.3)) / ($0.18 + ($0.05 x 2.3)) -1 = 46%, say 50%.

{T3} Calculation of electricity needed to produce 1 litre of liquid hydrogen

First, drawing on the empirical data from Iceland

13 MW for a year = 13,000 kW for a year = 13,000 x (24 x 365) = 113.9 x 10^6 kWh$_e$.

2,000 t liquid hydrogen = 2 x 10^6 kg.

Liquid hydrogen has a density of 0.070 kg/litre (McGraw-Hill, p. 338 of Vol.1, 8th edition).

So 2 x 10^6 kg would occupy 2 x 10^6 / 0.070 = 28.57 x 10^6 litres.

Thus energy expenditure per litre = 113.9 x 10^6 [kWh] / 28.57 x 10^6 = 3.99 kWh$_e$/litre.

Secondly, a theoretical evaluation of the energy needed to produce 1 litre of liquid hydrogen

Since electrolysis to produce hydrogen is 71% efficient, 1 kWh of electricity produces 0.71 kWh$_{th}$ of hydrogen.

Since liquefaction uses 30% of the energy in the hydrogen,

the energy needed for liquefaction = 0.71 x 0.30 = 0.213 kWh$_e$.

Thus 1 + 0.213 = 1.213 kWh$_e$ is sufficient to produce, and liquefy, 0.71 kWh$_{th}$ of hydrogen.

Thus 1.213 / 0.71 = 1.708 kWh$_e$ produces 1 kWh$_{th}$ of liquid hydrogen.

The heat content of hydrogen is 120 MJ/kg (McGraw-Hill, p. 338 of Vol.1, 8th edition).

Liquid hydrogen has a density of 0.070 kg/litre (McGraw-Hill, p. 338 of Vol.1, 8th edition).

So 1 litre of liquid hydrogen has an energy content of 0.070 x 120 = 8.4 MJ = 8.4 x 10^6 / 3.6 x 10^6 = 2.333 kWh$_{th}$.

Since it takes 1.708 kWh$_e$ to produce 1 kWh$_{th}$ of liquid hydrogen, the electricity needed to produce 2.333 kWh$_{th}$ (1 litre or 70 g) of liquid hydrogen = 1.708 x 2.333 = 3.985, say 4.0, kWh$_e$.

Cross-check that 1 litre of liquid hydrogen requires 4.0 kWh$_e$

70 g (1 litre in liquid form) of hydrogen contains 2.333 kWh$_{th}$.

30% of this is the amount of electrical energy needed for liquefaction, i.e 2.333 x 0.30 = 0.70 kWh$_e$.

Since electrolysis is 71% efficient, to produce 2.333 kWh$_{th}$ of hydrogen requires 2.333 / 0.71 = 3.286 kWh$_e$.

So total energy required to produce 70 g (1 litre) of liquid hydrogen = 3.286 + 0.70 = 3.986 kWh_e, say 4.0 kWh_e.

Replacing U.S. gasoline

A paper in the *Oil and Gas* journal by M.R. Simmons gave a figure, for US consumption of gasoline, of 8,286,000 barrels a day, as of March 2000. 8,286,000 x 365 = 3.02 billion barrels a year.

3.02×10^9 barrels = $3.02 \times 10^9 \times 42 \times 3.785 = \underline{\underline{480 \times 10^9}}$ litres.

US population in 2000 was 281 million.

So per capita consumption = $480 \times 10^9 / 281 \times 10^6$ = 1708 litres of gasoline per year.

Using a fuel cell, the amount of liquid hydrogen needed to replace this would be 1708 x 2.284 (see Appendix A) = 3901 litres of liquid hydrogen.

Direct electrical energy needed to produce 1 litre of liquid hydrogen = 4 kWh_e (as above).

So direct electrical energy needed to produce 3901 litres of liquid hydrogen = 3901 x 4 = $\underline{\underline{15{,}604}}$ kWh_e.

In 2001 U.S. consumption of electricity amounted to about 3.5×10^{12} kWh_e/yr.

So per capita consumption = $3.5 \times 10^{12} / 281 \times 10^6$ = 12,455 kWh/yr.

So extra amount of electricity required for gasoline substitution, by hydrogen, = 15,604 / 12,455 = 1.25 times present amount.

{T4} U.S. natural gas *production* has roughly flat-lined for the last twenty years, at around 19 trillion cubic feet a year (tcf/yr). In the year 2000, US natural gas *consumption* was about 22 tcf. Between 1985 and 2000, imports from Canada increased by about 2.5 tcf/yr, to make up the difference. The increasing imports from Canada *might* just be because Canadian gas was cheaper, so U.S. gas producers consequently saw little profit in making substantial investment to expand production. However, that does not appear to be the explanation; rather it is increased difficulty in obtaining the gas: Texas, which produces one-third of US gas, in 1999 had to drill 6,400 wells to keep up its production, whereas 4,000 were sufficient in 1998. Neither are Canadian resources unlimited: Canadians are having to drill nearly 7,500 wells a year to keep up Alberta's production.

Another reason for doubting that U.S. natural gas supplies can be regarded as "abundant" is that the Energy Information Administration have suggested that by 2015 the US may need 50% more natural gas than today, i.e. another 11 tcf/yr. The Energy Administration did not say where this was to come from.

{T5} To make 1 t of gasoline requires 3.65 t coal, including the coal needed to carry out the conversion process (Durrant, 1953:309). I do not know whether the process has changed since the 1950s, but if not, it appears that nothing like all the carbon in the coal is released during the conversion process. For data passed to me by a reliable source, science journalist Bernard Gilland, was that burning gasoline releases 63 tC/TJ, while the hydrogenation process for converting coal to gasoline emits 48 tC/TJ, for a total of 111 tC/TJ. Thus synthetic gasoline releases 111 / 63 - 1 = 76% more carbon per unit of energy.

{T6} The American Wind Energy Association estimate that it would be possible to install sufficient wind turbines to produce 675 billion kWh/yr onshore plus a further 102 billion kWh/yr offshore, for a total 777 billion kWh/yr.

Assuming a capacity factor of 25% (this is probably optimistic: over two years, four northern European nations achieved a mean of 22%), this would require an installed capacity of of $777 \times 10^9 \times 1000 / (24 \times 365) / 0.25$ = 354,794 MW, say 355,000 turbines each of 1 MW capacity.

Because of short term unpredictability in the wind, it is unlikely that all of this would be used (UK data suggests a 14% loss), but ignoring that, and since U.S. electricity consumption was (in 2000) about 3.5 trillion kWh/yr, the 777 billion is 22% of the whole.

Over the final three decades of the last century, U.S. population growth was 1.06% per year. $1.0106^{20} - 1 = 23\%$, so 20 years of population growth would absorb the additional 22% output.

The capacity factor of conventional power stations is somewhat variable. A 70% figure for conventional power appears in Trainer (1995:1018), but more recently I have been coming across a 60% figure (which is quoted in the text).

{T7} Liquid hydrogen has a density of 0.070 kg/litre (McGraw-Hill, p. 338 of Vol.1, 8th edition).

So 160 gms of hydrogen occupies 0.160 / 0.070 = 2.286 litres.

{T8} The energy needed to make 1 litre of liquid hydrogen is 3.985 kWh_e (see endnote 3), so to make 2.286 would require 2.286 x 3.985 = 9.11 kWh_e. Note that if this electricity had to be made by burning fossil fuel, then the energy required would be 9.11 / 0.33 = 27.6 kWh_{th}.

Note also that gasoline has an energy content of about 33.5 MJ/litre. Making the amount of hydrogen that has an equivalent motive power, namely 2.3 litre, would require 27.6 x 3.6 x 10^6 = 99.4 MJ.

{T9} The pressure of 930 atmospheres, about 13,700 psi or 960 kg/cm^2, is calculated on the basis of hydrogen behaving like an ideal gas. In a real gas the pressure is likely to be higher.

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THE CRUCIAL LIMIT: 11 CUBIC KM OF CARBON PER DECADE

By Andrew Ferguson

A figure which looms large in discussions of carrying capacity is 9 billion tonnes of carbon dioxide per year. This number is a rough estimate of the maximum annual emission from the burning of fossil fuels which is compatible with stabilization of the concentration of atmospheric carbon dioxide. We need to remind ourselves that the present concentration of this gas is 31% above the pre-industrial level; moreover we know from the Vostock ice core that it is now higher than it has been at any time in the last 420,000 years; furthermore, using information from sediments, we know it is likely to be higher than at any time during the last 20 million years. The significance of those points will be reflected in the closing sentences.

The 9 Gt/yr of carbon dioxide (or its equivalent, 9 / 3.664 = 2.5 Gt carbon) is of importance, because if every human being is to be allowed the modest emission of 4.5 tCO_2/yr, then, by simple arithmetic, *human population needs to be 2 billion*. In order to gauge the modesty of that 4.5 tCO_2/cap/yr, we may note that the average citizen of the USA emits about 20 t/yr, the average European 10 t/yr, the average Canadian and average Australian 16 t/yr.

Readers of these pages will appreciate that the notion that renewable energy could substantially replace fossil fuels — albeit widely canvassed — is a fantasy; therefore the 9 $GtCO_2$/year figure is a limit which applies while fossil fuels last, and deserves an in-depth study, which it hopefully receives herein.

Engelman (1994), in *Stabilizing the Atmosphere*, was the first to adumbrate the 9 $GtCO_2$/yr figure, though actually he gave a figure of 8.9 Gt (p. 27). On page 40, he filled in the background thus: "This was also the year [1990] used by the scientists advising the Intergovernmental Panel on Climate Change for their estimate that a 60 to 80 percent reduction in CO_2 emissions would result in stabilization of atmospheric concentrations of that gas at 353 parts per million." Note, incidentally, that Engelman uses 353 ppm as the 1990 carbon dioxide figure, whereas in *Vital Signs* (2002), p. 53, a figure of 354 is listed (a minor difference, only just worth noting). Using carbon emission data from the same *Vital Signs*, a 60% reduction implies an emission limit of 5.931 x 0.40 = 2.4 GtC/yr, and an 80% reduction implies an emission limit of 5.931 x 0.20 = 1.2 GtC/yr. Note that we have now switched to using carbon weights (following the recent tendency). The switch is easy, since 1 tC = 3.664 tCO_2. Note that the IPCC range of 1.2 to 2.4 GtC/yr, estimated as being required to achieve stabilization at the 1990 level of 353 ppm, lies below the 2.5 GtC/yr that we are considering here as a benchmark. We will comment on that again later.

On page 15 of *Profiles in Carbon*, Engelman (1998) sets out the background somewhat similarly thus:

> The Intergovernmental Panel on Climate Change (IPCC, a panel of hundreds of scientists working under UN auspices) suggested that at least a 60 percent reduction in CO_2 emissions from 1990 level would be needed to stabilize carbon dioxide concentrations at their 1990 level of 353 parts per million by volume.

There is a possible ambiguity as to whether that means a 60% reduction in emissions from burning fossil fuels, or a 60% reduction in all the emissions humans are responsible for. However, common sense makes the requirement clear. It would be unwise to anticipate decreases in the amount of carbon released from deforestation and change of land use, so it comes down to how much we must reduce our emissions from burning fossil fuels. That is what we will consider.

Our purpose here is not to just accept an IPCC figure, but to look at the underlying reasons, so let us start by taking a datum from page 10 of *Stabilizing the Atmosphere*, namely that there are 2.75×10^{12} tCO_2 in the atmosphere, or $2.75 \times 10^{12} / 3.664 = 750$ GtC. This is confirmed by a note to a diagram on page 23 of Houghton (1997), which gives 750 GtC as the weight of carbon in the air, as carbon dioxide, in 1990. While we may have doubts about climate models, we can surely trust scientists to calculate the weight of carbon in the atmosphere, after measuring CO_2 concentration in the air!

Combining this 750 GtC with the concentration of 353 ppm, we can deduce that each ppm is equivalent to 750 / 353 = 2.125 GtC.

It may not sound impressive when we hear that, over the past decade, the concentration of carbon dioxide has increased by 15.4 parts per million by volume (the 1990-2000 rate). Perhaps more striking is the thought that there has been an increase in the carbon held in the atmosphere, as carbon dioxide, amounting to 15.4 x 2.125 = 33 billion tonnes, *equal to 15 cubic km of solid graphite*. Note that we need to include the words, "as carbon dioxide," since carbon is also held in the air in the form of methane (CH_4), and other gases, which are also increasing.

Perhaps even more impressive is the thought that at the concentration of CO_2 in 2000, 369 ppm, the amount of additional carbon that is now in the atmosphere as CO_2, compared to the pre-industrial level of 280 ppm, is (369 - 280) x 2.125 = 189 GtC, more easily envisaged as a volume of solid graphite of 85 cubic kilometres.[a] Anyhow, whether that is a useful picture or not, let us follow our investigation further.

As a matter of simple logic, in order to stabilize carbon dioxide at any particular concentration, the following relationships must hold true:

(i) Excess emissions = yearly increment in atmospheric carbon.

(ii) Allowable emissions = annual emissions - excess emissions.

Accurate measurement of carbon dioxide concentrations only started in 1958. Working in decade-long periods (i.e. using increments based on an annual average over each past decade), we can work out allowable emissions as follows:

Allowable emissions in 1970: 3.997 - 1.870 = 2.1 GtC/yr[b]
Allowable emissions in 1980: 5.155 - 2.763 = 2.4 GtC/yr[c]
Allowable emissions in 1990: 5.931 - 3.294 = 2.6 GtC/yr[d]
Allowable emissions in 2000: 6.299 - 3.273 = 3.0 GtC/yr[e]

'Allowable emissions' is of course a shorthand for the emissions which are allowable *if the then current level of carbon dioxide is to be kept stable*. It may seem surprising that the 'allowable emissions' figure goes up; this is because when there is more carbon dioxide in the air, more gets absorbed by land and sea.

It may appear from these figures, that carbon dioxide concentration would stay stable at 1990 levels were we to emit about 2.6 GtC/yr (as carbon dioxide). That is possibly true, but note that in 1960, carbon emissions were 2.5 GtC/yr and yet carbon dioxide concentration had by then increased to 320 ppm from a pre-industrial level of 280 ppm. Anyhow as an approximation we can accept 2.5 GtC/yr, as it is not useful to try to pin down an accurate figure. For one thing, changes in the emissions from forest fires, and releases from land change, could make a significant difference to the limit for emissions from burning fossil fuels. What we can say is that the above calculations show that complicated models are not needed to see that the figure of 9 $GtCO_2$/yr (2.5 GtC/yr) is in the right ball park, and that the IPCC were probably wise to indicate a range of uncertainty, namely 1.2 to 2.4 GtC/yr as noted above. OPT uses the 2.5 GtC/yr only as a rough benchmark. For, as we now hope to show, the conclusions that stem from it are so dramatic that it would be a waste of time to strive for more accuracy.

A wider picture of the carbon cycle

Although it provides only background information, before we move on to consider the importance of the 2.5 GtC/yr figure, let us look at the carbon cycle in overall perspective, drawing from page 23 of Houghton, 1997.

The ocean contains a vast store of carbon, about 40,000 bn tonnes, which is fifty times the amount of carbon which is held in the atmosphere as carbon dioxide — 750 bn tonnes in 1990. But unless something happens to release the store, that figure is not important. What is important is the capacity of the land and sea to absorb carbon.

Roughly speaking, the land absorbs (by photosynthesis) 62 bn tonnes of carbon per yr (62 GtC/yr). Releases, by respiration and decomposition, are 60 GtC/yr. A larger cycle occurs in the ocean, with physical and chemical processes absorbing some 92 GtC/yr, with releases of 90 GtC/yr. Those numbers are only a general guide: some people hold that the land cycle is considerable larger. As mentioned, what is important is how much the land and sea can absorb; that can be assessed independently of how substantial the cycle is.

In his diagram, page 23, Houghton (1997) was giving figures for 1990, when he indicated that burning of fossil fuels releases about 6 GtC/yr, and deforestation about another 1.5 GtC/yr, for a total of 7.5 GtC/yr, and each year *an additional* 3.5 GtC/yr are left in the atmosphere. It is thus clear that the actual absorption of carbon, by land and sea, must be approximately 4 GtC/yr. If we regard the 1.5 GtC/yr from deforestation as fixed, this leaves 2.5 GtC/yr as the amount of carbon from fossil fuels which the Earth can absorb (as previously calculated).

Perhaps it should also be mentioned that we are simplifying matters by regarding most variables as fixed. For instance, apart from its desirability for other reasons, reducing soil erosion would have a very significant effect on reducing carbon release (Lal et al., 1999).

The importance of the 2.5 GtC/yr figure

It might be argued that it is of little importance to establish even a roughly correct figure for release of carbon by burning fossil fuels, because nations like India and China are hell-bent on increasing their per capita emissions to something closer to that of the developed world. However, OPT would argue that it is sensible for us to aspire to influence nations which do not have similar equitable claims to increase their emissions. The USA, Europe, Canada and Australia are all examples of nations that fall into this category.

Let us take the USA as the prime example. In 1990, with a population of 250 million, it was emitting 1.347 GtC/yr from burning fossil fuels. In the past decade, U.S. emissions have increased in parallel with its population. During the three final decades of the last century, U.S. population was increasing at a rate of 1.06% per year. At that rate of growth, *by 2050 the annual emissions of the U.S. alone will be exceeding the global limit of 2.5 GtC/yr* (equal to 11 cubic km of solid graphite per decade).[f] Thus it is hard to exaggerate the importance of the U.S. curtailing its population growth.

It can be argued that there is an alternative solution, namely to reduce per capita emissions. However, the two options are different in kind. Reducing per capita emissions is something which can be achieved with only the greatest difficulty, insofar as it is almost certain to meet with the strenuous objection of voters, with a risk of the Government becoming the Opposition. The alternative option, reducing population growth by allowing only balanced migration (equal numbers going out as coming in) is something that is desired by the majority of the population of not only the U.S., but also of Europe, Canada and Australia. The challenge is for the popular will to overcome the combined forces of the commercial world, politicians and economists. That is a particularly difficult task for the USA, where politicians only achieve office by the support of wealthy élites. The U.S. is the pre-eminent global threat, but Europe, with emissions of about 10 tCO_2/cap, and Canada and Australia, with 16 tCO_2/cap, could also contribute something to the greatest challenge facing the human race today, namely to prevent Earth from returning to a 'water age' (see *Ice Age, Glacial and Interglacial*, OPTJ 2/1, pp. 24-26). What is required is simply this: a reduction in fossil fuel emissions from the current figure, equivalent to 28 cubic km of graphite per decade, to 11 cubic km per decade. As mentioned, it is only conceivable that this might be achieved with a global population of about 2 billion.

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Notes

a. Graphite has a specific gravity of 2.22 = 2.22 t/m^3.
189 Gt at 2.22 t/m^3 = 189 / 2.22 = 85 x 10^9 m^3 = 85 km^3.

b. 1960-70, yearly increment in atmospheric carbon ((325.5 - 316.7) / 10) x 2.125 = 1.87 Gt.

c. 1970-80, yearly increment in atmospheric carbon ((338.5 - 325.5) / 10) x 2.125 = 2.763 Gt.

d. 1980-90, yearly increment in atmospheric carbon ((354.0 - 338.5) / 10) x 2.125 = 3.294 Gt.

e. 1990-2000, yearly increment in carbon content ((369.4 - 354.0) / 10) x 2.125 = 3.273 Gt.

f. 1.347 [GtC in 1990] x 1.0106^{60} = 2.54 GtC/yr. While it is hardly significant, it may be of interest to note that the figure of 1.347 GtC/yr is taken from Engelman (1994) and actually includes cement production. Since cement production is only about 2% of the whole, it barely affects the calculation, but it would probably be wiser to exclude the carbon dioxide released in cement production from the calculation, since we now know, from the Biosphere 2 experiment, that cement gradually absorbs carbon dioxide as it sets, and this may largely, if not totally, cancel out what is released during production.

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KEEPING AN EYE ON THE BROADSHEETS

collected by James Duguid

Jim Duguid does a sterling job for OPT in keeping an eye on the media, mainly with reference to his national newspaper the *Scotsman*. What follows are some extracts from the cuttings he has sent to me.

Christopher Maclullich's letter to the *Scotsman*, 21st April, 2003, about the fundamental weaknesses of capitalism, went like this:

> First, the organizing principle of capitalism renders valueless all processes of nature and society that are not priced in the market and are not inputs to commodity production.
>
> Capitalist exploitation of natural resources for commodity production and capital accumulation often ignores ecological processes that are essential for the regeneration of these resources. At a frightening rate, the world is being stripped of sources of fresh water, forest, fertile soil and biodiversity as a result of market-driven approaches to natural resources.
>
> Secondly, capitalism ignores the perspectives of the huge numbers of people whose needs are not satisfied through market mechanisms. Economic growth has often caused poverty and social dislocation for those removed from previously viable and sustainable traditional livelihoods.
>
> In a finite and ecologically connected world, nature's limits need to be respected by curtailing the excesses of capitalism.

Two days later, in the *Scotsman* again, correspondent Dan Buglass reported:

> The UK has lost an estimated 10 per cent of its most productive arable land in the last 20 years, a "squandering of irreplaceable resources," according to Professor John Hillman director of the Scottish Crop Research Institute.
>
> In an article in the institute's annual report, Prof Hillman and two of his senior colleagues, Donald McKerron and Jim Duncan, say that in 1981 the UK had slightly more than five million hectares of good arable land. By 2000, that had shrunk to less than 4.5 million.

Buglass went on to point out that the effects of the shrinkage were masked by better farming methods, but he did not point out that modern farming methods are highly dependent on high energy inputs, and they will become expensive as fossil fuels become scarce. But energy is being discussed too. The problems of using renewable resources, because of their intermittency, was brought out in a letter by Dr Wilson Flood (21 April, 2003):

> To argue that the power will come from hydro-electric or from other renewable sources betrays an ignorance of how the system operates, since these are already part of the installed capacity. . . .
>
> The proposals in the white paper are quite alarming. Coal-fired and nuclear power stations are to be phased out by about 2050: at present they contribute 55 per cent of the UK's electricity. Their output will be replaced by renewables and natural gas-fired stations.
>
> This will result in rapid depletion of the UK natural gas supplies, since gas is also a primary fuel in its own right and is a major source of heating for domestic and industrial uses.
>
> The UK will need to import nearly all of its natural gas requirement by 2020 . . .

Unfortunately, Flood went on to dismiss the world's emissions from burning fossil fuels (amounting to 23 billion tonnes of carbon dioxide a year — a figure which of course he did not mention) as being irrelevant to global warming. Like many economists, he believes his own judgement to be better than that of the several hundred scientists who comprise the Intergovernmental Panel on Climate Change.