

Why Implementing the Space Option Is Necessary for Society

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Abstract

For several years, specialized agencies have been searching for "new programs" that could reinvigorate the support for space activities and stop their budgets' decline of. But the same time, they have been retrenching by focusing on collecting and distributing information, putting scientific research as their core projects. On a planet soon to host a ten-billion population that will impact the biosphere's workings as never before, at a time when many governments and organizations see the virtue in the management of scarcity, musing on the origins of life and of the Solar System can hardly be expected to be invested with high priority. The Space Option arose from the analysis of the issues confronting humanity. In reviewing the material needs of the human population in the near future, the analysis finds that the impact on the biosphere will perforce be much larger than it usually seems to be acceptable to assume.

1 Introduction

For several years now, specialized agencies have been searching for "new programs" that could reinvigorate the support for space activities and stop the decline of their budgets. At the same time, however, they have been retrenching by focusing on collecting and distributing information, putting scientific research as their core projects.

"Exploration, not exploitation" is the croaking slogan echoing nowadays. On a planet soon to host a ten-billion human beings population that will impact the biosphere's workings - literally - as never before, and in a world where a growing number of governments and international organizations are declaring scarcity management as the uppermost virtue, semi-philosophical musing on the origin of life and of the Solar System can hardly be expected to be invested with a higher priority than any other ludic activity. The survival of the specialized agencies - the game directors - will come to enjoy a similar irrelevance. The (past) members of the space community may collect enough energy to mourn their passing: the citizens of the world's nations will keep worrying about food and shelter and fighting for some shares of those. The Space Option (Bernasconi & Woods, 1993) has not been defined primarily for the defense of the agencies' privileges: rather, it rose originally from the analysis of the issues confronting humanity. To the insiders, it has been argued that only if such a concept is at the core of their program planning their entities can have hopes to survive (Bernasconi, 1995a), but the Space Option Concept responds to much deeper ethical demands (Bernasconi, 1995b).

The present study returns to the discussion of the real world's issues as the drivers for taking the Space Option. The basic material needs of the human population in the near future are reviewed: water supply, metabolic energy inputs from the biosphere, other renewable resources of biologic origin, industrial power generation needs, and other material resources.

The astronautical endeavour of the Space Option, deeply anchored by a bidirectional thread in the optimistic and libertarian vision of modernity, is obviously not the (inexistent) panacea for all the ills of our time, but it represents the only approach that allows beginning to work out solutions for those ills and thus enable the conservation of a humane world -- a world in which even intolerance can be tolerated, not one in which it must become the ruling doctrine.

2 The Space Option: Summary and History

"Can there then be a single right answer when it comes to the natural role of man (who is a part of nature ...)? Isn't it natural for man to transform the world around him as much as comets or asteroids [have done]? To terraform entire planets in centuries to come?" -- Franklin Wayne Poley, 1997.

It has been pointed out (s.e.g. Ehricke, 1976; Sheffield, 1986) that at the center of the current crises is the fact that most humans still look at planet Earth as if it were the whole Universe; as we wrote in introducing the Space Option Concept (Bernasconi & Woods, 1993): "While most people do acknowledge - at least on the intellectual level - that the Universe is extremely large, they assume that the relevance of this same Universe for the human affairs is nil." This mind set is far from being alien to contemporary scientists: thus, some paleontologists and biologists have opposed the Alvarez hypothesis for the Cretaceous extinction wave because an asteroid's impact is an unnatural intervention in the Earth's environment represented -- yet: "Impacts do happen!"

The consideration of the Universe as a real factor in human history is thus refused on non-rational (i.e. ideological) grounds. Artificial boundaries are imposed on the human field of action and their presence is verbally explained as motivated by "realism" or "fairness" or "education:" the evolutionary argument for Astronautics is thus read backwards, the interrogations raised by the Fermi paradox are answered in terms of a (suicidal) "cosmic justice." Entering space is no longer seen as the historical test that determines whether a civilization persists, but as the possible pastime of a civilization that has managed to survive its growth remaining enclosed on its planet.

The Space Option concept has its origins in the aspiration for a positive, hopeful future: as it has been mentioned, it is intrinsic in the thought of the astronautical pioneers (see the discussion of Astronautics and astronautical humanism in Bernasconi, 1995a), and has been explicated by a few contemporary researchers, Krafft Arnold Ehricke (1917-1984)

foremost among them (for a -- much too short -- summary of his work, see the "Space Option History" Section in Bernasconi & Woods, 1993).

Originally, the Space Option was defined basing on:

- the use of extraterrestrial resources, not for in-situ utilization
- their (or their products') import to Earth, to provide for a conspicuous fraction of the primary needs of ground-based societies
- a sense of urgency for beginning its implementation
- a limited time window during which humanity can take this Option.

Both significance and efficacy of the Space Option were implicitly acknowledged, mainly on the basis of common sense, of the awfulness of its mainstream alternative, and of the comparison of a number of world system dynamics model runs (Martin, 1985; Schultz, 1988

Yamagiwa & Nagatomo , 1992; Yamagiwa, 1993). In this way, however, the Space Option Concept conserved the bases of the ecozist ideology that had started its attack on the world with just the world dynamics methodology. The concept could therefore be misunderstood as Malthusian or sharing the same methodological weakness of the totalitarianism that it is designed to avoid. An effort was therefore undertaken for more explicitly assessing the ethical and evolutionary position of the Space Option (Bernasconi, 1994, 1995b). In parallel, work was begun to review the *quantitative* aspects of the human society's needs in the near future. Food requirement have received a first assessment (Bernasconi, 1997a), as have power needs (Bernasconi, 1997b) and raw materials (Bernasconi, 1997a).

The Space Option has found its way into Europe's Long-term Space Policy Committee (LSPC), that has mentioned it in its first report. It has been offered (without great success) to the space agencies, as a path to their strict survival (Bernasconi, 1995a). Its message continues to be spread through educational talks, contributed papers (Creola, 1994, 1997a) and as a theme at future-oriented Symposia (Creola, 1997b; Bernasconi, 1997b; Engelberg, 1998).

Both quantitative analyses and trends observation have continuously confirmed the strong exigency for the astronautical endeavour: the insiders' behaviour has similarly tended to confirm that the Space Option is much more significant than the old space program -- and as Hansson (1997) has pointed out, the business of our common future may well be taken up in space by agents without any connection to that old program.

3 Earth vs. Space

"Quite aside from the life-or-death practical matter of who will win the next war, ..., is the unavoidable moral problem: do we, with our acres to waste on golf courses and parks and tobacco fields, have the right to hang on to what we hold? Or are we, as our brothers' keepers,

morally obligated to accept ... millions as fast as they can be shipped to us? ... I have not been able to find a moral answer which pleases me; nevertheless I know my answer-- ... I'll fight before I'll let the spawning millions... roll over [us]" -- Robert A. Heinlein, 1954.

The Earth intercepts around 100,000 TW of solar power and, by photosynthesis, all the plants of the biosphere yield a biomass production equivalent to some 100 TW, while the overall energy use by humanity is of the order of 10 TW and its mere metabolic requirements will soon surpass 1 TW. These relationships are essentially ignored in the energy discussions and they are seldom invoked in the technical analyses: when they are, it is most often to "show" how abundant the resource is and to negate the need for novel technological approaches. (It is not surprising that today the majority of this arguments come from the same sources that invoke energy rationing, since ideological stances have no need for logical arguments.) Under the best conditions, one encounters factual and balanced analyses striking a note of alarm - and yet still failing to sufficiently discriminate between the metabolic and the industrial energy needs, and by consequence between the methods to comply with them (Czihak, Langer, & Ziegler, 1976).

In reality, the gross relationships between the anthropogenically-controlled and the total solar power flows, on the one hand, and between the biosphere's primary production and the human metabolic needs are as irrelevant as they appear to be insignificant. However, this does *not* mean that the anthropogenic effects are negligible just as does *not* mean that the biosphere can provide abundant energy to satisfy our needs. (Nor, of course, it means that energy rationing, redistribution, etc. have any rational basis.)

The following Chapter presents a simple attempt to quantify the basic material needs of humanity at-large in the 21st Century: water, food, fibers, power, raw materials. It will emerge that, independently from any financial analysis, these needs are simply too large to be satisfied by an exclusively Earth-based economy, without major (and, because of the stakes for humans and for life, unacceptable) risks of environmental degradation and conflicts within and between societies.

4 The Material Needs of Humanity in the 21st Century

"The idea of finding gold on the Moon... is usually greeted by space skeptics with the assertion that there is almost certainly more gold right here on Earth than on the Moon, and only a fool would go that far away in hopes of finding it. This argument blindly neglects one crucial point. The know gold supplies on Earth are already owned by someone. To the person who does not own the gold mines of Earth, the transportation problem associated with obtaining gold from the Moon may appear less risky that the formulation of political uphevals or downright stealing necessary to obtain gold on Earth." -- E.P. Wheaton, 1966.

Every thinking person, as soon as she reaches the age where the daily news can be appraised, begins to wonder about issues such as: "Will there be enough food for everybody?" "Can

humanity get sufficient power to maintain civilization?" "How will the increasing amounts of garbages be disposed off?" Indeed, such questions are as old as our species and have traditionally taken precedence over other, more poetic ones, like: "Where do we come from?" We have heard literature teachers qualify this second category of questions as "adolescential" and, while we find it logical that adolescents are upset by such qualification, having long outgrown that age we are inclined to agree with it. It seems one of the many inconsistencies of current times, when the expression "judeo-christian tradition" has been made into something of a snipe, that so many people base their normative perception of the future on *their own* interpretation of Jesus' word: "You keep asking yourself: what shall we eat, how shall we cover ourselves? Look at the birds and the lilies in the field" etc.

"Dominus providebit" is a confession of faith in the Lord. But in absence of faith and of the readiness to personally contribute to the work of the Providence, it becomes a lazy substitute for a thinking policy. Today, given many people's distorted understanding, it must be ideologically translated into a pantheistic: "Natura providebit," against a picture in which humans are neither part of nature as other animals, nor creature called to raise above it, but rather beings outside and *below* nature. How else can one, if not explain, at least penetrate the paradox of the "redistribution ideology"?

On the contrary, when following an ethical impulse to act for the better, one does raise those prosaic questions and attempts to formulate answers: for instance, F.W. Poley (1997) has proposed the following list of "ecological problems to be solved for the human enclave":

1. enough space.
2. food and water.
3. energy supply.
4. materials supply.
5. aesthetics - smell, noise, visual.
6. toxicity of waste and by-products.
7. others?

In this Chapter, we address the material aspects of this lists (mainly the points 2-4).

4.1 Water.

Water is the most precious and most necessary resource. In per capita terms, its need can roughly be assessed as follows (based on 1990 US usage):

- potable water - drinking, cooking - 40 l/d
- very clean water - personal hygiene, washing, commerce - 460 l/d
- clean water - irrigation, industry - 2500 l/d
- power generation - 2000 l/d

In other words, the order of magnitude needed is around 5 m³/d/person. For 10 billion people, the yearly consumption is accordingly of the order of 18.25 10¹² m³, or 18,250 km³. Over the Earth's land surface, this is equivalent to 122.5 mm water/a (0.34 mm/d). Rain precipitations being an order of magnitude larger, one could conclude that there will be no problems. It is however known that problems are already occurring, and that in certain areas freshwater is being "mined" through net extraction from aquifers.

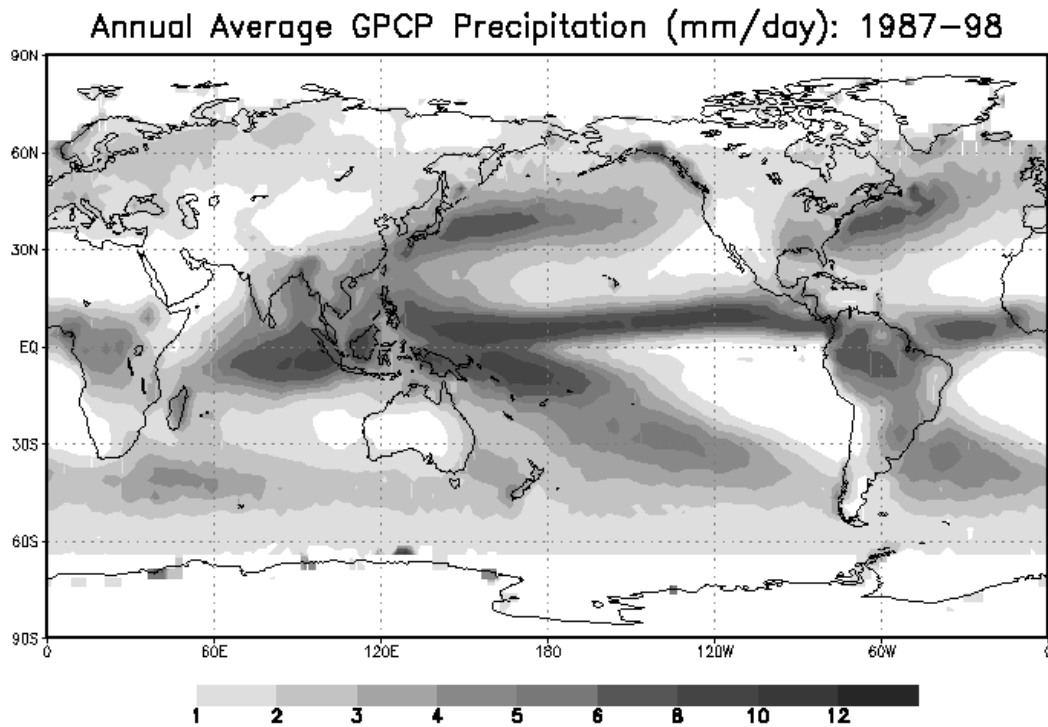


Fig. 1: 1988-1996 annual average precipitation [mm/d] (GPCP graphics)

The most intense precipitations occur over the oceans and the tropics: most of the continental areas receive less than 2 mm/d (Fig. 1); also, rainfall is not distributed uniformly in time, leading to a mismatch between water use and availability. This associated with the evaporation loss: precipitation returns to the atmosphere as vapor some 40 times per year, on the average.

By far the greatest water quantities are used in connection with food production and power generation: correctly innovative approaches to those issue will reduce the need for the associated water resources.

4.2 Food

Food is the basic resource (after drinking water) mandatorily needed by all human beings. The FAO energetic recommendations have been used as a starting point to assess the equivalent power need by the human population for metabolic purposes. On average, a person requires 0.13 kW: Since about 80% of the human nutriment is of vegetable origin (Czihak, Langer, & Ziegler, 1976), the equivalent power consumed by 10 billion people is of 1.3 TW, and can be broken down as:

- 1.04 TW from vegetables
- 0.208 TW from herbivores
- 0.052 TW from carnivores.

Table 1 summarizes the production power flows in the biosphere for the primary producers (photosynthetic plants), the primary consumers (herbivores), the secondary consumers (predatory carnivores), and the tertiary consumers (second-order carnivores).

	Primary Producers	Primary Consumers	Secondary Consumers	Tertiary Consumers
Ecological efficiency	-	16%	11%	5.3%
Land ecosystems	68 TW	10.9 TW	1.24 TW	0.07 TW
Oceanic ecosystems	34 TW	5.5 TW	0.62 TW	0.03 TW
Biosphere Total	102 TW	16.4 TW	1.86 TW	0.10 TW

Table 1: Ecological Efficiency & Consumers Foo

Under the assumptions that, for the human-raised plants and animals, the alimentatively usable fraction amounts to 50% of the gross production, it results that more than 10% of the output of the Primary Producers from the overall biosphere will soon have to be diverted just to feed the human population. If only the land ecosystem is considered, the proportion increases by a factor 1.5 (when only the 14-million-km² surface currently under cultivation is considered one arrives at an impossibility, i.e. more than 116% confirming that other ecosystems will increasingly have to be exploited for food and forage production).

When I prudently concluded (Bernasconi, 1997a) that "space food production will not yet be a necessity in the 21st century," I only referred to the fact that the above numbers show as physically possible to feed ten billion humans off this planet: they are not to be interpreted as an assertion that this will be probable or easy or safe. The fractions above are indeed optimistic particularly since no losses, wastes, spoilages, etc. have been assumed in the

calculation. Furthermore, the provision of a healthy diet is a more delicate balance act than obtaining the necessary power, with an almost endless list of possibilities for hygienic, social, economic, industrial, and political troubles.

Use / Commodity	Net Need	Global Primary-Production Equivalent	Fraction of Global Production
Vegetable food	1.04 TW	2.08 TW	2.04%
Herbivore animal food	0.208 TW	2.60 TW	2.55%
Carnivore animal food	0.052 TW	5.91 TW	5.79%
Total	1.3 TW	10.59 TW	10.38%

Table 2: Energetic Equivalent of Human Nutritional Needs

4.3 Fiber, Timber, & alia

The burden placed on the biosphere by the human population is increased further given that, contrast with other animals, humans also require:

- garments and shoes,
- shelters and furnishings,
- fuels for cooking their food,
- fuels for heating and for lighting their dwellings.

That only a fairly advanced technological base can provide for these needs by substituting materials other than of biological origin becomes obvious when one considers that the use of such resources for these purposes remained predominant throughout the world until early in this century. And these commodities conserve an important economic role to this day. There are many uses for natural products of biological origin beyond simple nutrition:

- Textile fibers -- both of vegetable (cotton, flax, hemp) and animal origin (wool, silk)
- Resins (rubber, plastics raw materials)
- Beverages (coffee, tea, cocoa)
- Wood products -- for construction, for furniture, for paper and pulp, as fuel
- Hides (leather)
- Raw materials for dyes and paints
- Miscellaneous products -- essences, pharmaceuticals, drugs, etc.

In energetic terms, it is estimated that only the first four classes are significant enough to be considered here.

4.3.1 Wood Products

Wood use is the next most significant biospheric factor: in 1995, almost 400 million m³ of wood were consumed in the U.S. alone, and 280 million t were used globally for paper and pulp products.

The unit requirement for the wood commodities in the 21st-century society has been assessed from the specific values for selected countries, reported in Table 3 and based on UN/ ECE data. Note that the figure estimated is about one-third lower than the recent per-capita use in the U.S.

		Unit (1000s)				
		US	EU	Germany	CH	Used
Fuelwood	m ³	0.34	-	0.05	0.12	0.17
Sawnwood	m ³	0.54	0.16	0.21	0.26	0.30
Panels	m ³	0.16	0.07	0.14	0.11	0.16
Woodpulp	t	0.24	-	0.07	0.08	0.16
Paper & paperboard	t	0.35	0.12	0.20	0.22	0.24
Wood in the rough	m ³	1.52	-	0.38	0.43	1.04

Table 3: Estimating the Baseline Need for Wood in the Next Century

With the conversion values given by Anon. (1987) and a decrement by 10% (because of different uncertainties), one arrives at some 730 kg/a/person, equivalent to 13,870 MJ/a/person or 440 W/person. Given that the primary productivity of woodland ecosystems varies between 0.79 - 1.2 W/m² (computed from data in Flindt, 1995) and under the assumption of a 50%-efficiency, the per-capita land requirement is of 730 - 1110 m². The total area under exploitation will have to be of 9,220,000 km², or almost half of all the woodlands in temperate regions. In terms of power flow from the primary producers, the global requirement is of 4.40 TW.

4.3.2 Fibers

Fibers are also quite a significant in terms of primary production. The current cotton production has reached almost 20 million t, and represents 45% of the world use of textile fibers. Synthetic fibers (polyamide, polyester and acrylic) accounted for 43%, cellulosic fibers (including acetate and rayon fibers) represent about 6%, and wool accounts for the remaining 6% of textile fibers produced worldwide.

Cotton is a highly energetic product: while its yield can vary by 10% or more from year to year, the average yield can be estimated at 70 g/m² (basing on USDA national data). If this

value is compared to the net primary production of a cultivated field (around 0.65 kg/m²/a, corresponding to 11.7 MJ/m²/a, derived from Flindt, 1995), the equivalent energy content of cotton is of 167 MJ/kg.

Taking a shearing yield of 3.78 kg wool, more than 380 million sheep are necessary to sustain the world's production (1.4 million t). The equivalent metabolic power of a sheep being 60 W, the energy requirement for the global herd is of 22.8 GJ, corresponding to 45.6 GW on the trophic plane of the primary producers (always assuming a 50% in the use of the forage). In mass-specific terms, the wool energy equivalent amounts to 1001 MJ/kg.

	Usage	Current Production [million t]	Energy equiv [MJ/kg]	Int Projectd [kg/a/p]	Use Power equivInt [TW]
Cotton	45%	19.3	167	4	0.212
Wool	4%	1.437	1001	0.3	0.095
Cellulosic fibers	6%	0.232	? (34)	0.1	0.001
Total	-	1.884	(221)	4.4	0.308

Table 4: Energetics of Natural Textile Fibers

In energetics terms, the remaining natural fibers (including silk) are orders of magnitude less significant than cotton. To estimate the per-capita need, a use of 4 kg cotton per person was taken as a reasonable middle ground: the historical data (1994-95) show large geographical variations, ranging from highs of 9.2 kg/person (US) and 3.6 kg/person (China) to lows of 3.2 kg/person (Europe) and 2.4 kg/person (India). The amounts for wool and cellulosic fibers have then been taken as proportional to the current consumption and the total production has been scaled with the population. Other fibers, such as: jute, kenaf and allied fibers - 2.7 million t, sisal and other hard fibers - 0.37 million t, add to the burden.

4.3.3 Resins

Natural rubber covers a still growing fraction of the world's usage, a fraction that reached 40% in 1995 with a global production of 6.1 million tons. The yield of rubber plantation trees is given as better than 1700 kg/ha, or 0.17 kg/m²: this must be compared with the primary production of tropical woods (1.2 W/m²) to arrive at an equivalent energy content of the order of 7 W/kg or 223 MJ/kg. Motor vehicle production plays the primary role in natural rubber consumption, a fact that - together with the growing trend towards the manufacture of value added rubber products in natural-rubber producing countries - helps explaining the per-capita usage figures. These show the total rubber consumption to have averaged, in the 1990-

1994 period, upwards of 10 kg/person in U.S. and Canada, almost 8 kg/person in the European Community, and around 15 kg/person in Japan and south-east asian countries.

Which baseline value should be taken? In terms of a global average, it seems more reasonable to point at 2 than at 6 kg/a/person for the natural rubber use. The required global production would then be for 20 million t, and for 222 MJ/kg the primary producers' power flow would be 0.14 TW.

Consideration should also be given to the production of natural oils and fats, where 1.62 million t of technical oils alone were obtained in 1995, when however they constituted less than 1.7% of the total production of these commodities.

4.3.4 Beverages

Three major agricultural commodities can be associated with warm drinks: coffee, cocoa, and tea. Global yearly productions in this decade have averaged less than 5.8 million t of coffee (green beans), 2.5 million t cocoa beans and of made tea; given that cocoa derivatives are highly caloric, however, this commodity can be considered as an alimentary product.

The 1996 average yields amounted to 53 g/m² for coffee and to 117 g/m² for tea, both values being approximated: when referred to primary productivity of cultivated lands (0.39 W/m², or 12.30 MJ/a/m²), the corresponding equivalent energy contents reach 233 MJ/kg for coffee and 105 MJ/kg for tea.

To assess individual consumption level, one can observe that, in 1994, 1.31 million t of coffee were produced in Brazil that exported 0.87 million t while letting its stocks decrease from 1.01 to 0.98 million t: if the remaining 470,000 t were used in the internal market, this corresponds to 3.07 kg/a/person. In the same year, the average specific consumption can be estimated at 5.49 kg/person in the EU countries and to 4.36 kg/person in North America. If one sets the production objective for the future for the availability of 5 kg/a/person, a plantation surface of 94.9 m² per individual will be needed: the equivalent power flow allocation is then of 0.37 TW.

As for tea, China has produced 610,000 t of tea, and exported 184,000 t -- which leaves 426,000 t for domestic consumption, or about 0.35 kg/person; the EU countries imported 214,000 t (0.58 kg/person); Japan produced 87,000 t and imported 41,000 t more (1.02 kg/person); the U.S. imported 96,000 t (0.37 kg/person). With a baseline estimate at 0.6 kg/person, one arrives at an individual plantation fraction of 5.1 m², a worldwide surface requirement for 51,020 km², and an equivalent primary producers' power flow of 0.02 TW.

Use Commodity	/ Net Need	Global Primary-Production Equivalent	Fraction of Production	Global
Wood Products	2.20 TW	4.40 TW	4.31%	
Textile fibers	n/a	0.31 TW	0.30%	
Natural Rubber	n/a	0.14 TW	0.14%	
Beverages	n/a	0.39 TW	0.38%	
Total	--	5.24 TW	5.14%	

Table 5: Energetic Equivalent of Non-Nutritional Biological Products for Human Use

4.3.5 Summary

One has to conclude that, if serious attempts are to be made to better cover the human needs (food, clothing, construction lumber, wood fuel) of the worldwide population in the 21st century, a fraction of at least 1/6 (but probably significantly larger) of the biosphere's global primary production will have to be dedicated to this single species. Thus, even though the fraction will remain smaller than unity, all ought to be aware and very conscious of the fact that the consequent impact on the "natural world" will be very large. It can further be noted that the largest part of the resources sequestered for human usage are for nutrition purposes, and rightly so, both because of the priority and of the uniqueness of this requirement. On the other hand, any fashion that tries to increase the amount of terrestrial natural raw materials for other uses (e.g. plastic production, fuel) must - in the medium-term - be viewed as a perversion of priorities: the rationale objective of any "planetary management" must be to unburden the biosphere from the tasks of directly supplying technical items that can be obtained otherwise.

4.4 Power

4.4.1 The Technological Animal

The homo species have moved beyond mere biological evolution by extending their control beyond what biology itself controls, i.e. the body. These exosomatic implements (that collectively are referred to as "technology") are fundamental for the survival of man, and in particular for the survival of billions of persons now abroad on this planet and demand separate exosomatic energy flows for their creation and maintenance. And the power needs for such non-metabolic (or industrial) uses are quantitatively far more significant than the metabolic uses, though a very significant first investment is the one needed to obtain food.

Society	Energy [GJ/ha]	Input Food [GJ/ha]	Harvest Population [person/km ²]	Density Power [W/person]
Foraging	.001	.005	0.01	320
Pastoralism	.01	.04	1	32
Shifting agriculture	0.4 - 1.5	10 - 25	10 - 60	77
Traditional farming	0.5 - 2.0	10 - 35	100 - 950	8
Modern agriculture	5. - 60	29 - 100	800 - 2000	68

Table 6: Energy in Food Provision: The Long-Term Picture (adapted from Smil, 1990)

4.4.2 Energy Subsidies for Food

Agricultural technology has been important for supporting an increasing population density but, in modern times, the needed energy subsidy has become quite large and currently amounts to half the recommended nutritional energy level (Table 6 - Smil, 1990). It must be understood that only this energy subsidy has prevented the Malthusian predictions from coming to pass: and if these subsidies were no longer available, three-quarters of the human population would be eliminated during the next thirty years.

In Table 7, a shorter time interval is examined: the historical data are from Smil (1990), to which we have added some future projections. Two scenarios have been obtained by assuming, in the first case, that the energy subsidy and the subsidy density continue to grow, but that after 2000 the ratio between the subsidy and the energy in the harvest stabilizes; in the second case, all three parameters continue their historical growth trend. In this case, the energy subsidy equals the energy of the harvest before the year 2000.

The final energy subsidies are equivalent to power levels of 0.96 - 3.17 TW (96 - 317 W/person).

4.4.3 Biomass Fuel

Biomass has often been mentioned as a potential contributor toward satisfying future industrial power needs. The discussion in Section 4.3 has shown, however, that human population has grown to an extent that makes it ill advised to also burden the biosphere with industrial requirements beyond those for relatively few, specialized products. Refuses from agricultural and woodland activities may be available for power generation, in which case nothing speaks against such use: often, such refuses are better returned to the fields as part of measure to maintain the topsoil's fertility, or they may be brought to better uses than burning. In such cases, again, the rational approach is to invest the residual biomass for tasks where

its specific qualities are exploited and to procure power through other technological means. Reference to Tables 2 and 5 shows that such refuses are available (in equivalent power terms) for 3 - 10 TW: of course, the upper value not only would imply that the preceding guidelines have been disregarded, but also require some complex processing that would reduce the eventual energy yield significantly. Thus, biomass power seems to be limited, in a rational world energy system, to something around 1 TW -- and 0.1 kW/person does not even suffice to cover the agricultural energy subsidy needs. The fuelwood item, included among the wood products, adds 0.065 kW/person.

	1900	1925	1950	1975	2000	2025
Population [billion]	1.7	2.0	2.5	4.0	6.0	10.0
Cultivated Area [106 km ²]	11	12	12.5	14.6	14	13
Population Density [p/km ²]	155	167	200	274	429	769
Food Harvest [EJ]	6	9	12	25	50	83
Yield [MJ/m ²]	0.545	0.75	0.96	1.712	3.571	6.385
Energy Subsidy [EJ]	0.1	0.5	1.5	8	18 - 60	30.3 - 100
Subsidy Density [MJ/m ²]	0.01	0.04	0.12	0.55	1.29 - 4.29	4.66 - 15.38
Energy Available [W/p]	112	143	152	198	264	263
Subsidy/Harvest Ratio	0.017	0.056	0.125	0.32	0.36 - 1.2	0.0365 - 2.41

Table 7: Energy in Food Provision: Into the 21st Century

4.4.4 Specific-Power Needs

Throughout history, the power level available to each person has increased from the kilowatt level of agricultural societies to the ten-kilowatt level of industrialized countries. Intrinsic (technical) and esthetic factors have allied themselves with economic ones in yielding a continuous growth of efficiency in the use of energy: this efficiency can be externalized through economic relationships, such as amount of wealth produced with a unit of energy. If economic wealth is real, however, there probably is (and it seems there is) a minimum energy investment necessary for its accumulation, and the progress of efficiency can only be asymptotic. Under the best conditions then, one could argue on the basis of an asymptotically-decreasing energy investment to yield a unit of wealth, compensating an asymptotically-increasing per-capita wealth; thus, in the best of the worlds - with a stable population - the total energy usage would be constant.

A present-day average for industrialized countries is around 7 kW/person: while the above-mentioned improvements in wealth-specific energy efficiency may decrease the requirements by about one-third, a modest expansion of the material wealth envelope (e.g., 0.8% per year) would full compensate that reduction within half a century. On the other hand, new energy

costs will probably appear as the world becomes increasingly crowded that may increase demand significantly. Accordingly, one ought to look for power sources to provide at least 5 and possibly 15 kW/person, or between 50 - 150 TW globally.

Of course, the *net* power used could be reduced through electrification -- but (in terms of biospheric impacts), this measure only has a meaning if the power station is located outside the biosphere! In such case, we would need to import only 25 - 35 TW of electricity.

4.4.5 Summary

The results of the above discussion are collected in Table 8, where the aggregate values are also compared with the relevant resource of this planet. It is seen that an Earth-centered approach requires the use of 17% of the total rainfall over the continents, sequester for human use the equivalent of 16% of the global primary production and release into the biosphere an heat flow equal to 27% of the energy flow through the all the vegetation of Earth. These are, in our opinion, staggering proportions: the major problem associated with them is the assumption that usage and sequestration will indeed be possible to begin with.

The last column in Table 8 gives the values for the case in which humanity breaks out and begins implementing the Space Option by acquiring sufficient power from space. While the fraction of primary production diverted for human use only decreases to 15%, the needs for water drop by more than one-third, to 10%, and the thermal burden is smaller by a factor of 3, down to 8.4%. Of course, such an approach would also do away with other burdens (chemical, toxic, etc.) that have not been addressed in the present study.

4.5 Materials

Can the use of extraterrestrial resources be economically justified? After all, it is "common knowledge" that nothing material is worth enough to be brought from space to Earth. But when the world will be confronted with scarcity, not only the economics of raw materials will change, one will also have to factor in the very real risks of conflicts over those limited resources. Then, the standard Cornucopian reply -- that scarcity shall never arise because it never did in the past -- will be of scant help; nor will the ecologist philosophy -- make do with less -- help defuse such risks.

Use / Commodity	Net Global Terrestrial Path Need	Space Path			
		Global Production Fraction Equivalent	Global Production Fraction Equivalent	Global Production Fraction Equivalent	Global Production Fraction Equivalent
Water	18,250 km ³ /a	18,250 km ³ /a	16.78%	10,950 km ³ /a	10.07%
Human Nutrition	1.3 TW	10.59 TW	10.38%	10.59 TW	10.38%
Wood Products	2.20 TW	4.40 TW	4.31%	3.75 TW	3.67%
Fibers	n/a	0.34 TW	0.33%	0.34 TW	0.33%
Resins	n/a	0.21 TW	0.20%	0.21 TW	0.20%
Beverages	n/a	0.39 TW	0.38%	0.39 TW	0.38%
Power Generation	30 TW	150.5 TW	27.9%	44.9 TW	8.4%
Total - wrt Primary Production	-	15.93	15.62%	15.28	14.98%

Table 8: The Biosphere's Burden for Hosting the 21st Century Human Population

An well-quoted paper about the future availability of nonrenewable materials is that by Goeller & Zucker (1984): interestingly some of its conclusions that are hardly substantiated by the data it offers. Of sixty-six elements surveyed, Goeller & Zucker (1984) found that indeed twenty-nine (or 44%) will have been depleted by *more than 100%* in 2100, while the reserves for only fourteen elements will still be greater than 90%. After this first round of analysis, 'extended resources' for the depleted elements are invoked, and for four elements the depletion rate is estimated to fall below 10%; but for no less than fifteen elements, the depletion *remains* greater than 100% or is simply not updated. In summary, in only about 29% of the cases, the situation seems unproblematic (<10% depletion), in 48% it may well be critical (>10%), and for 23% of the elements it will impossible (>100% depletion). The authors reflect this result by acknowledging that "many important elements will be in inadequate supply" -- but how can they then conclude by affirming that "shortages will be at most only transient events and ... [the] population will not be ... impoverished by the lack of materials"?

However, the Goeller & Zucker (1984) analysis lets the consideration of extraterrestrial resources become even more sensible, when the type of the "extended resources" is examined. In all fifteen cases in which these are successful in avoiding depletion during the 21st century, recourse to either low-grade ores or to seafloor nodules is invoked. For sure, the mining such materials within the biosphere will be associated with large environmental risks, generating correspondingly high costs. Furthermore, those authors estimated that about \$100 billion/year would have to be invested over the next century, to let their predictions become reality: but processes to use low-grade or seafloor ores are not in place. Clearly, the size of the market,

the need to obtain the materials, and the hazard to an environment already strained for supplying unique and indispensable products, argue in favor of developing those technologies for space mining and processing, keeping in mind that this way shortages can truly be truly eliminated and the environmental burdens truly removed from the biosphere. 5. Additional Problems "Historically, spaceflight has had a philosophical purpose: to carry man to the stars. [...] build the machines that will allow man to escape the confines of Earth and explore the Universe, and expand the realm of the human race." -- Michael A.G. Michaud, 1973.

Poley's (1997) list is not yet exhausted: but for now, we can only briefly touch upon some of those points.

4.6 Enough Space

In terms of physical space, Astronautics obviously discloses the entire Universe and - even more modestly - the geolunar space offers plenty of it. For this to have an influence in terms of living space, however, one will have to wait for the era of true space colonies. Thousands, even millions, of space residents (as can be projected in the early stages of the Space Option implementation) will in no way decrease the pressure on Earth.

But that space can be reached and, once the pressure is large enough, something can be done in actuality for acquiring it. Toxicity of waste & by-products

In nature, wastes tend to be toxic by nature, and lose their toxicity by (i) separation from the producer, (ii) dilution in the environment and (iii) reprocessing by third agents. As the previous Chapter has shown, the 21st-century humanity taxes the biosphere's capabilities for diluting and reprocessing its biological wastes -- for nature may be able to cope. Greater problems arise in connection with the toxicity of those exosomatic activities that are the characteristic and the need of our species. The "division of labor" between Earth and Space, advocated by Ehricke, is the first step for reducing this sort of toxicity. The use of space separate the wastes of the human exosomatic activities from the body of the biosphere. Dilution may or may not follow, depending on the case; in space, reprocessing of all matter can be expected to become the rule. Aesthetics

The Space Option provides some more, and somewhat cleaner, living space by moving industrial activities away from Earth. At the same time it offers the capabilities for conserving unique terrestrial domains, and the wealth and power for landscaping and restoring damaged areas; it also opens new sceneries to the examination of humans, to their visit, and to their creativity.

Ethical actions are also aesthetically appealing: a work well done is beautiful.

4.7 Other Issues - Governance

Beyond the problems that Poley (1997) correctly labeled ecological, there is a similar list of political problems. Among them, we may list:

- increasing disenfranchisement of the citizens, both through the remoteness and the diffusion of power
- a passive acceptance of overcrowding
- a blind enamourment with gigantism

The Space Option can contribute to mitigating such issues through the change in perspective that the associated change in proportion will bring about. With the resources of the solar system available, people will no longer accept, will no longer have to accept, that there is only one solution to a problem -- and that in most cases the solution does not cause closure. The power, the resources, and - yes - the technologies and the knowledge acquired through the hard work of implementing the Space Option will enable different solutions to all problems, solutions that indeed change the conditions. 6. Conclusions "Instead of attempting to find more energy resources, [the ecologist] argument falls in to the Flat-Earth Fallacy. It presupposes that we must continually slice a finite energy pie into thinner and ever-thinner portions, so that everyone can have an equal share. "Yet if our supplies are truly finite and our numbers continue to grow ... sooner or later the shares get so thin that we all starve to death. Equally." -- Ben Bova, 1981.

Within a generation's time span, this planet will have to provide for the basic needs of ten billion human beings. Never before has such a large fraction of the global biosphere production been consumed by a single animal species: more than one part in ten just for basic food. The impact on nature will be enormous, in not necessarily overwhelming. No amount of human nature reform can make this fact undone. Practical difficulties may amply increase its difficulty and may lead to conflicts with potentially fatal outcome for at least humanity.

But humans do require more than just food: as the present review has shown, for other applications the equivalent of more than 7% of the total production of the land ecosystems has to be sequestered. No neosophic developments can lead to persons that live naked, without shelter and eat their food uncooked. It is highly probable that humans will continue to survive in a human fashion, i.e. along the cultural lines that their ancestors have adopted for the last 250,000 years, give or take 100,000 years.

Homo sapiens, however, is the "technological animal," that in the simplest terms means that the individuals of this species cannot survive without the support of technical implements. This necessity begins with the effort for providing food, where the agricultural technology requires significant energy subsidies to obtain ever more produces from a roughly constant surface under cultivation. Industrial power, however, is as significant in human culture as metabolic power is for the individuals -- and just as there, it must continuously be supplied

afresh. There is no way to emend the Second Law of Thermodynamics. Energy is the basic ingredient for all activities -- and is in particular associated with the generation of wealth.

The three existing ground-based power generation technologies that can satisfy the 21st century needs over a period of the same order are: coal, nuclear fission, and terrestrial solar systems. But their use would have dramatic climatic consequences, as exemplified by the fact that they would release into the biosphere heat for about 28% of the amount flowing through the Earth's vegetation.

It is only by accessing the resources of space that the human burden on the biosphere can be lightened, and successively reduced. It is only by taking the Space Option that enough resources can be made available to humanity, giving a reasonable hope that permanent conflicts over scarcity can be avoided. Even immaterial resources (aesthetics, hope in the future) can come to humanity only through the Space Option.

It is therefore largely irrelevant that the Space Option is also the best policy for the space agencies to assure their continuation: the major issues in the real world ought to force our movement in its direction, with or without a space program. The astronautical endeavour of the Space Option, deeply anchored by a bidirectional thread in the optimistic and libertarian vision of modernity, obviously is not panacea (that does not exist), but is the sole approach that can enable the conservation of a humane world -- a world in which even intolerance can be tolerated, but does not have to become the ruling doctrine. Acknowledgements

This paper presents the results of independent work done by the authors. They would appreciate receiving your comments and thoughts on implementing the Space Option Concept as the first step on the path towards an Astronautical Humanism: they can be reached by e-mail at cris_berg@hotmail.com. They also maintains an Internet Web site dedicated in particular to the discussion of the relevance of Astronautics for the future and to the associated use of extraterrestrial resources (URL: <http://www.geocities.com/ResearchTriangle/9738/>).

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- Anon, 1987, Conversion Factors (Raw Material/ Product) for Forest Products. UN Rept. ECE/TIM/55 (1991).
- [Marco C Bernasconi](#) and Arthur R Woods, 1993, "Implementing the Space Option: Elaboration and Dissemination of a New Rationale for Space - Part II: The Space Option", paper [IAA.8.1-93-764b](#).
- [Marco C Bernasconi](#) (1995a), 1995, "Astronautics - A New Product for Agencies' Space Activities", a "Space 2020" Position Paper on Astronautics. Paper presented at the "Space 2020 Round Table," ESTEC, June 28-29.
- [Marco C Bernasconi](#) (1995b), 1995, "Ethics and the Astronautical Endeavour - Introductory Considerations", paper [IAA-95-IAA.8.1.01](#).
- [Marco C Bernasconi](#) (1997a), 1997, "Broadening Space Utilization through Space Resources Exploitation: The Survival Mode - Why Extraterrestrial Resources Are Necessary", a position paper for the International Workshop on "Innovations for Competitiveness," ESTEC, 19-21 March.

- [Marco C Bernasconi](#) (1997b), 1997, "Space and Energy", paper presented at the Symposium "Space Visions for the 21st Century," Kuffner Observatory, Vienna (Austria), 4-5 September.
- Ben Bova, 1981, "The High Road", Houghton Mifflin Co., Boston (MA)/ Pocket Books, New York (NY), 1983.
- Peter Creola, 1994, "Has Space A Future?", address to the Annual Meeting of the Swiss Academy of Technical Sciences, Bern, 22-23 September; also: [ESA](#) Bulletin 82 (1995), 6-15
- Peter Creola (1997a), 1997, "The Long-Term Future of Astronautics", (in German), Address to the "Space Days," Swiss Museum of Transports, Lucerne (Switzerland), 25 April-11 May.
- Peter Creola (1997b), 1997, "Space Visions for the 21st Century", Keynote address to the Symposium "Space Visions for the 21st Century", Kuffner Observatory, Vienna (Austria), 4-5 September.
- Krafft A Ehrliche, 1976, "Astropolis and Androcell - The Psychology & Technology of Space Utilization and Extraterrestrialization", paper presented at the Intl. Space Hall of Fame Dedication Conference, Alamogordo (NM); AAS Science & Technology Series 45, 373-396.
- Forum Engelberg 1998 - Workshop "Spaceship Earth."
- Rainer Flindt, 1995, "Biologie in Zahlen", Fischer.
- H E Goeller & A Zucker, 1984, "Infinite Resources: The Ultimate Strategy", Science 223, 456-462.
- Anders Hansson, 1997, "The Enduring Realities of Space Economics", A position paper for the International Workshop on "Innovations for Competitiveness," ESTEC, 19-21 March.
- Robert A Heinlein, 1954, "Tramp Royale", Ace Books (1986).
- Anthony R Martin, 1985, "Space Resources and the Limits to Growth", [JBIS](#) 38[06], 243-252.
- Michael A G Michaud, 1973, "After Apollo", Spaceflight 15[], 362-367.
- F W Poley, 1997, Science Court / The Scientist Citizen. Comments posted in the "Future Cities" discussion group, 26 February and 3 March.
- F W Schultz, 1988, "The Effects of Investment in Extraterrestrial Resources & Manufacturing on the Limits to Growth", [JBIS](#) 41[11].
- Charles Sheffield, 1986, "On Timeline Singularities, Space, & Human History", Far Frontiers VII, 2-19.
- Vaclav Smil, 1990, "General Energetics - Energy in the Biosphere and Civilization", J. Wiley & Sons, New York (NY).
- E P Wheaton, 1966, "Space Commerce", AAS Science & Technology Series 10, 340-358.
- Yoshiki Yamagiwa & Makoto Nagatomo, 1992, "An Evaluation Model of SPS Using World Dynamics Simulation", Space Power 11[02], 121-131.
- Y Yamagiwa, N Kaneda, & Y Ishikawa, 1994, "An Evaluation Model of Development of Energy Resources in Space Using World Dynamics", System Dynamics Review [02], -.