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Putting Space Resources to Work

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Abstract

Resource development in remote places on Earth has depended on government attitudes toward regional development, transport and local production costs, economic accessibility of external markets, and the availability of local markets. The initial stages of space resource development may well depend on a government-funded lunar science/engineering base for initial markets.

I. Introduction

If traveling in space were as cheap as riding a railroad and if the costs of mining and manufacturing in space were low enough to make space-based industries competitive in terrestrial markets, then the debates over space budgets would have long since ended. We would be established on the Moon by now, deep in study of it as a planet and using lunar mass drivers to launch a steady stream of raw materials to orbital manufacturing facilities where a growing list of products would be made under the special conditions of weightlessness and/or high vacuum. We might well have prospected a few near Earth asteroids and found some of them rich enough to cause nervous tremors in the precious metals markets. And we would certainly be spending plenty of time and money building resorts in orbit, on the Moon, and on Mars, probably to the considerable annoyance of the scientists.

In reality, space travel and space development are far from cheap, and the present list of space products is very short : communications links, earth reconnaissance, science, national security, and national prestige. Virtually all space activities (except the now mature comsat industry) depend on government funding in one form or another for their

very existence, and are likely to do so for a long time to come.

The economic picture will begin to change as we establish manufacturing capabilities in orbit, gain access to lunar and asteroidal materials, and then acquire capabilities in orbit and/or on the Moon to make most of what we need out of those extraterrestrial resources. However, the very high cost of space operations may well mean that the present, near-total reliance on governments to supply R&D funds and provide markets for space-related goods and services may continue until quite late in the process. Lunar and orbital facilities may achieve a high degree of operational self-sufficiency (in the sense of reduced reliance on Earth for resupply) long before any measure of economic self-sufficiency is achieved. However, it may be possible to structure the form of government investment in a way that will bring about economic self-sufficiency at the earliest possible time.

In this paper, I will briefly describe examples of resource development in some remote places on Earth and indicate the importance of such factors as government attitudes, transport and local production costs, the economic accessibility of external markets, and the availability of local markets. The cases include the Antarctic mainland which has no near-term prospects for resource development, the North America Arctic where resource development has been driven almost entirely by economic factors, the Siberian Arctic where resource development and industrialization has been driven more by strategic and political factors, and early Australia where development depended entirely on the local markets created by the British penal settlement.

2. Terrestrial Resource Development

2.1 Antarctica

During the 1950s, when continuous occupation of the continent first began, there was some talk about the possibility of mining and other commercial activities.^[1,2] It seemed unlikely that such a large land mass would be barren of significant mineral resources, a point of view subsequently strengthened by the results of plate tectonics studies which suggest continuities with mineral rich regions of southern Africa and Australia. There now seems little doubt that Antarctica is a vast storehouse of mineral wealth. However, there has been very little prospecting to date and, except for the continental shelf where the

prospect of krill fishing and petroleum exploration have generated serious discussion, there is no prospect of any Antarctic economic activities in the near term.^[3]

The economic sterility of the Antarctic continent is almost entirely a consequence of the cost of dealing with ice and snow. Access to the continent - by sea during a brief period in the summer and intermittently by air during the rest of the year - is expensive, but the dominant ice-related factor is the presence of permanent land ice of great thickness. The ice cap makes finding and reaching potential ore bodies all but impossible, and also means that any construction must use ice/snow foundations. Insulation is difficult (although not impossible); snow accumulations and ice movements cause additional expense.^[1,2,4] There is certainly little chance that Antarctic products other than scientific knowledge and similar intangibles will soon reach global markets, nor is there much chance that anything other than melt water will be produced for local use.

The Antarctic has resources, but development costs are prohibitive, given that the only conceivable markets for Antarctic products are global.

2.2 North American Arctic

Although there has been as yet relatively little development in the northern parts of Alaska and Canada, the potential is enormous, thanks mostly to the absence of permanent land ice and also to relatively easy access to major markets and suppliers.^[4] Although sea access is restricted to a brief summer period and even then must often be supported by icebreakers, movement by road, railroad, and pipeline is feasible. The Mackenzie River also plays a role in the transportation network. Roadbeds and pipelines must be carefully constructed to minimize thermal contact with the permafrost but, once built, provide relatively inexpensive connections with major Canadian and American markets and suppliers.

Thus far, resource development in the region has proceeded slowly and at a pace determined primarily by short term economic factors. Neither the US nor the Canadian government has yet perceived any pressing need to develop the north and, indeed, both are still attempting to sort out conflicting economic, environmental and social priorities. In Alaska, even such basic issues as resource ownership and land use policy have not yet been fully resolved. In the absence of active governmental support for development, most costs

are borne by commercial developers who, out of economic necessity, have very narrowly defined interests. High costs ensure that only large, concentrated deposits of the highest-value minerals (most often oil) have been exploited. The resulting narrow geographic focus ensures that the utility of any facilities or local transportation systems will end when the deposit is exhausted. Consequently, commercial developers have increasingly opted to recruit a commuting labor force. For instance, most Prudhoe Bay workers actually live in Anchorage, spending one week on the North Slope and then one week at home. Although the cost of flying people back and forth is considerable, it is still much less than the cost of building short-lived towns and of providing community services. The oil companies pay significant taxes and royalties to the state of Alaska and, through it, help support the city of Anchorage. If, as the Prudhoe field is exhausted, other fields are developed, the oil companies will save considerable sums by not having to relocate the work force or the communities in which they live.

Resource development in the North American Arctic is currently driven by global market forces. High costs focus attention on high value products. Only in Alaska, where the state government has the power to tax extractive industries, has a substantial population base been established, and then only in Anchorage. The pace of development could increase if the global demand for minerals and other natural resources increases or, as in the case of Alaska which has developed a taste for a high standard of living, if existing sources of regional financial support begin to erode.

2.3 The Siberian Arctic

Development of the Siberian Arctic is relatively advanced, mostly due to a long-standing national commitment to the region, but also because several major rivers provide year round transport.

Siberian development is largely a 20th century phenomenon. Previously, there had been only a minor Russian presence east of the Urals: the mountains, together with the sea ice that chokes the coast eastward of Murmansk and a lack of east-west river transport, effectively isolated all of Siberia. The region became linked with Europe and the Pacific coast only after completion of the Trans Siberian railroad in the 1890s. Although the

railroad runs through the southern parts of Siberia, it gives access to several major rivers that flow north into the Arctic Ocean. The rivers can carry barge traffic during the navigation season and trucks after freezeup.^[4]

Although the railroad was built during the Tsarist period, significant development of the Siberian Arctic began in earnest during Stalin's reign. The first major push came as a result of Stalin's insistence that the Soviet Union become independent of foreign supplies of raw materials, despite the fact that high development cost would make domestic supplies more expensive than those available on world markets. Strategic considerations and a shortage of foreign exchange made this an attractive choice. The second major phase of Siberian development came during World War II when the German invasion threatened to destroy the Soviet Union's industrial base.^[5] Following 1940, whole industries were moved east of the Urals, creating significant local markets for Siberian resources. The most recent phase has resulted from the dramatic increase in world petroleum prices. In order to bolster domestic supplies and earn foreign exchange, during the 70s and 80s the Soviet Union has made massive investments in the development of petroleum reserves in the far north. A conscious decision has also been made over the years to establish industrial centers in the north; Noril'sk is a prominent example. It is not clear how cost effective such centers are. They tend to be located near major concentrations of raw materials, but the difficult physical conditions and a low level of services has made it difficult to attract and keep workers, despite substantial wage differentials. The size of the effort is indicated by the enormous population of the Soviet Arctic. Even if one excludes the heavily developed and relatively accessible Kola Peninsula/White Sea regions, the Soviet north had a 1975 population of three million, about twenty times the population of comparable regions in the US and Canada (excluding Anchorage).^[6]

Development of the Siberian Arctic has been driven primarily by political and strategic considerations. The Soviet Union has been willing to invest heavily in the region in order to achieve resource self sufficiency and to establish a definitive Russian presence east of the Urals.

2.4 Penal Australia

A final example of some interest is that of the early stages of British settlement near Sydney. In the cases examined thus far, local markets have either been nonexistent or, in the case of the Siberian Arctic, have played only minor roles in stimulating development. The Australian case is of considerable interest because development was totally driven by local demand, even though that demand existed only because the British government established a prison colony at Sydney in 1788.^[6]

Distance from Europe (and the attendant high cost of transport) played three major roles in Australian development. First, distance made Australia an attractive prison site: few convicts and ex-convicts were able to make their way home. Second, high transport costs guaranteed that, until the unforeseen development of the wool industry in the 1820s, few Australian products were able to compete in global markets. And third, the cost of supplying the colony was so high that local production of food, clothing, and other goods was both encouraged and profitable. The prison created its own market for goods and services and supported the growth of what turned out to be a most vigorous local economy.

Development of Australian resources beyond the immediate needs of the local community were impeded not only by overseas transport costs but also by a shortage of navigable rivers. Only when saturation of local meat demand forced entrepreneurs to begin breeding sheep for wool production did expansion into the interior grasslands begin. Wool was valuable enough to stand the high costs of internal and overseas transport and was the continent's first major export. In turn, the wool industry provided early financial support for railroads that permitted development of grain and mineral production in the interior.

Despite prohibitive transport costs, the Australian economy was bootstrapped into existence because the colony provided a service to the British government—supporting a prison settlement. Local markets supported economic development long enough for the first export to emerge.

3. The Development of Space Resources

The extraterrestrial resources that seem amenable to development during the next

several decades fall in two broad categories: those valuable enough to be marketable on Earth, and those saleable only in space. For the moment, we will consider only mineral resources.

There was a flurry of interest in the space community in the late 70s over estimates that, at then current world prices, kilometer- sized nickel/iron asteroids would each be worth one trillion dollars.^[7] About half of that value represented the nickel content and most of the rest the platinum-group metals. The cost of retrieving and processing such large objects was estimated at about 20% of the value. Although such an analysis completely ignores the market impact of quantities of metals large enough to justify the required capital investments, it doesn't seem too far fetched to imagine strategic interests providing incentives for small-scale extraction of precious metals from more common types of asteroids. In 1980, global production of nickel and platinum groups metals (much of it from the USSR and South Africa) were each worth about \$3.5 billion, a demand far too small to support significant investment in space development.^[8] Extraction of asteroid metals for sale in terrestrial markets will be undertaken once the industry can share transport systems with other space operations. The industry will contribute to the broader development of space resources and capabilities only to the extent of such sharing and/or to the extent that it provides royalty revenues which are then re-invested in space development.

Most other materials have no reasonable prospect of direct terrestrial markets. It is very much a matter of coals to Newcastle. The utility of most extraterrestrial resources (including the the bulk of asteroid metal production) will only be realized in space. There, because of the very high cost of transporting materials up from the surface of earth, extractive industries can tolerate high capital and operations costs and still be competitive in space based markets. The simplest examples are, of course, lunar oxygen for use for transport between lunar orbit and the lunar surface, and lunar soil used to shield large orbital facilities. The problem is creating markets for these raw materials in space.

In the long term, space based manufacturing enterprises will create substantial demand for a wide range of extraterrestrial materials. These may be enterprises devoted to products that can only be made in space, or may be enterprises displaced from Earth into orbit or onto the lunar surface by the economics of environmental protection or some

other cause. However, it seems unlikely that such manufacturing enterprises, of themselves, could bear the huge startup costs of the necessary transportation systems and extraction industries. As with Australian wool, pre-existing, government-sponsored markets for raw materials and basic services seem essential.

The development of extraterrestrial resources will begin under a set of circumstances that has no exact analog in terrestrial experience. In absolute terms, space materials may be as expensive as their Antarctic counterparts, but at least have the potential of space-based markets. As with Arctic oil, asteroidal metals have the potential to provide revenues to support other space activities but there is serious question as to the maximum supportable revenues. Global oil revenues of \$400 billion per year can easily justify the construction of multi-billion-dollar pipelines and support substantial northern development; but a \$7-billion-dollar precious metals industry can not plausibly support the development of new space transportation systems, let alone finance the development of lunar or asteroidal resources. And, finally, while explicit government support of space development will be essential in the early stages, the high costs and intangible nature of the early returns will so restrict government activities that the resulting demand would be too small to promote rapid development. There is certainly no prospect of bootstrapping ourselves into space on a Siberian scale in the next few decades.

On the whole, this would seem to be a gloomy assessment, particularly if we were to consider only short-term economic factors in formulating space policy. Realization of the potential of space resources is going to require a long-term commitment, but the Australian analogy suggests a way in which the emergence of space-based enterprises can be encouraged. In our thinking about space development we might substitute a lunar science/engineering research base for the prison settlement. Such a base would create demand for transport systems, small scale resource development, local manufacturing, and (eventually) a space based work force. Enterprise devoted to markets other than the base itself might be able to emerge without having to incur inordinate start up costs. What seems to be required is a long term commitment to a lunar base development program. Given the development of the next generation of heavy lift vehicles, it might be reasonable to imagine a lunar base commitment defined in terms of 1000 tons delivered annually

to LEO.^[6] Initially, 90% of base structures, and 2% each of supplies and equipment for a lunar oxygen (LUNOX) production plant.^[9] Use of LUNOX for near-Moon transport would allow a substantial increase in the delivery of equipment and structures. Local production of heat shields (for the journey to LEO), food, and construction materials would result, probably well within two decades, in a mode of lunar operations in which most of the 1000 tons would be devoted to staff rotation. Duty tours of 6-12 months, would permit a staff of several hundred. At this point, if members of the staff were encouraged to become permanent residents, staff size and base capabilities could increase substantially, providing the foundation of further development activities.

It seems impossible to predict just where such activities might lead, but it does seem certain that, unless the costs of space operations decline very dramatically in the near-future, space resources will be used almost exclusively in space and that the initial markets for those resources must be provided by governments. A lunar base, in particular, could provide markets and also provide the excuse to learn the engineering skills we will need to make large-scale use of space resources a reality.

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