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AN ASSESSMENT OF THE MINERALS AND MATERIALS SUBSTITUTIONS EFFORTS OF THE BUREAU OF MINES

Report of the

Committee on Mineral Resources Technology

National Materials Advisory Board
Commission on Engineering and Technical Systems
National Research Council

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The report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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See inside back cover for abstract

ABSTRACT

This report presents assessments of the efforts of the Bureau of Mines in two areas of its mineral resources technology program: alloy substitutes research, which deals with substitution of plentiful domestically available metals for imported strategic or critical metals, and minerals substitutes research, which deals with the development of strategic or critical mineral supplies from nontraditional domestic sources.

The alloy substitutes work represents a greatly augmented and expanded effort for the Bureau. In 1982, much of this work, which had been reprogrammed in response to the National Materials and Minerals Policy Research and Development Act of 1980, was just beginning and a detailed, project-by-project critique was considered premature. Thus, general observations are presented concerning such things as a comprehensive strategy for alloy substitution research, alloy development as a traditional industrial research forte, long-run high-risk project support, and cooperative agreements between the Bureau and nongovernmental organizations. Recommendations focus on the need for establishing clearly defined goals, identifying equipment and manpower needs, determining optimum levels of support, redirecting programs to more long-range activities, continuing contract research, expanding cooperative agreements, continuing joint sponsorship of symposia and workshops, increasing levels of expertise in alloy development, and concentrating alloy substitution work at a single research center.

Substitute raw materials research and development is a traditional Bureau pursuit. Given the poor economic condition of the domestic mining, milling, and ore processing industries, it is noted that the Bureau must continue to expand its efforts in this area if the nation is to reduce imports of critical and strategic materials and remain competitive in world markets. The observation, already recognized by the Bureau, is made that there is an overemphasis on development of nonbauxitic processes for recovering aluminum from domestic nonconventional resources, and it is recommended that the scale of these efforts be reduced and that increased emphasis be placed on chromium, nickel, cobalt, manganese, and the platinum metals. Also recommended are increased Bureau efforts concerning improved recovery of nonferrous metal by-product elements (especially in *in situ* leaching), potential recovery of additional elements from seafloor nodules, alternative potash resources, improved recovery of P_2O_5 from phosphate rock, and recovery of additional materials from solar salt bitterns. It also is noted that many of the issues affecting increasing imports are institutional rather than technical and that it therefore may be important for the Bureau to provide for deeper consideration of such issues.

PREFACE

In 1980, at the request of the Bureau of Mines of the U.S. Department of the Interior, the National Materials Advisory Board established the Committee on Mineral Resources Technology to provide an ongoing assessment of the materials aspects of the Bureau's Mineral Resources Technology Program. Emphasis was to be on identifying gaps and suggesting opportunities for making the program as effective and responsive as possible to national needs. During 1982, the committee continued its efforts and examined in greater depth selected portions of the program areas considered the previous year (i.e., the Bureau's efforts in minerals thermochemistry and materials substitutes).

This report presents the results of the committee's evaluation of the Bureau's materials substitution efforts. An on-site assessment of the Bureau's research centers at Albany, Oregon and Rolla, Missouri was performed by committee members John J. deBarbadillo and Harold E. Goeller. They were joined for the Albany visit by committee chairman Nathaniel Arbiter, committee member Milton E. Wadsworth, liaison representative Kenneth W. Mlynarski, and staff officer Richard M. Spriggs. Accompanying them for the Rolla visit were liaison representative James T. Dunham and staff officer Spriggs. Committee member Wadsworth also visited the Bureau's Salt Lake City, Utah research center. The initial draft of this report was prepared by Messrs deBarbadillo and Goeller.

It should be noted that several months have elapsed since the on-site assessment was completed (in September 1982). In the intervening period, the Bureau has already implemented a number of changes anticipated by the recommendations of this report and the on-site discussions held between committee members and Bureau staff.

This report has been reviewed by the committee and by outside reviewers. Readers should keep in mind that this report deals only with a limited portion of the total Bureau of Mines effort in mineral resources technology. Reports evaluating other parts of the effort are being published separately, as will be the committee's overall report on the mineral resources technology effort.*

On behalf of the committee, I would like to thank those who participated in this project. Special thanks are extended to the directors and staffs of the Bureau of Mines research centers at Albany, Rolla, and Salt Lake City.

Nathaniel Arbiter
Chairman

*As a result of a recent reorganization of the Bureau of Mines, the nonmining portion of the Mineral Resources Technology Program is now identified as the Minerals and Materials Research Program.

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INTRODUCTION

The Committee on Mineral Resources Technology has been charged with providing an ongoing assessment of the Mineral Resources Technology Program of the Bureau of Mines and especially with identifying gaps and suggesting opportunities for making the program as responsive as possible to national needs.

During 1982 the committee was asked to assess in depth those portions of the program dealing with minerals and materials substitution efforts. The overall program for 1982 focused on three general topical areas: advancing mineral science and technology, conserving domestic mineral resources, and developing domestic mineral resources. That portion of the program devoted to developing domestic mineral resources included 15 projects concerning the use of plentiful resources and 34 projects concerning substitutes for critical and strategic minerals.* The critical and strategic materials project area represented a Bureau of Mines response to requests from the industrial community and directives from Congress and federal agencies to develop research programs aimed at reducing U.S. dependence on imported strategic and critical materials. It included ongoing projects that had been reprogrammed into the new area as well as a number of new projects in the physical metallurgy-alloy development field. Because the new projects represented an important and greatly expanded Bureau effort in several areas of metallurgy, the NMAB Committee on Mineral Resources Technology was requested to review these activities in detail.

Bureau projects typically are distributed among the various research centers according to available manpower, equipment, and traditional industry orientation. During 1982, members of the NMAB committee visited the Bureau research centers at Albany, Oregon; Salt Lake City, Utah; and Rolla, Missouri. Projects being conducted at these centers were

*In the broadest context, critical and strategic minerals or materials are considered to be those that would be needed to supply the military, industrial, and essential civilian needs of the country during a national emergency and are not found or produced in the United States in sufficient quantities to meet such needs.

discussed in detail with the element managers, research supervisors, and, in many cases, the project scientists. Information on additional projects was available from committee members who had visited other Bureau research centers during the previous year.

It was immediately apparent that the projects included in the area identified as "substitutes for critical and strategic materials" covered a broader spectrum of research than the area title would suggest. In fact, some of the projects were unrelated to the substitution theme, and the project docket was subsequently redefined to eliminate this confusion.

The following review of the Bureau program has been restricted to a consideration of two aspects of the substitution effort: minerals, which actually deals with the development of strategic or critical mineral supplies from nontraditional domestic sources, and alloys, which includes substitution of plentiful, domestically available metals for imported strategic or critical metals. Although the minerals area is at most a reclassification or reorientation of some ongoing Bureau activities, the alloys area represents a greatly augmented and expanded effort. Since the two program areas are quite distinct, their reviews are presented separately in this report.

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ALLOY SUBSTITUTES

Awareness that different materials can fill the same end-use requirements probably is basic to the development of industrial society. Contrary to the impression one might draw from recent trade literature, organized efforts to seek substitutes for scarce or expensive materials undoubtedly predate the time when metallurgy was recognized as an engineering discipline. Substitution itself is a rather broad subject involving the interchange of alloying elements within a basic alloy system, the interchange of alloy systems with alternate nonmetallic materials, and the use of composite products.

The number of applications in which materials are interchangeable is great and many quite commonplace materials are involved. Consider, for example, the container industry in which coated steel, aluminum, glass, paper, woven fibers, plastic, wood, and animal hides all vie for a share of a multibillion dollar business. Substitutions of one of these materials for another occur constantly in response to changes in energy and raw materials availability, production costs, recyclability, and service requirements.

Historically, industrial research on alloy substitutes has been concentrated on improving properties or reducing raw materials costs and only during occasional shortages, especially during World War II and the Korean conflict, were major substitution efforts undertaken. In some cases, research aimed at developing substitutes for scarce metals has produced generally applicable results. One example is in the area of the hardenable grades of alloy steel. Originally, these were single alloy materials of rather high alloy content. Research projects in several laboratories over a period of years demonstrated not only that hardenability could be provided by a number of interchangeable elements, but also that the elements were synergistic in their effects. As a result, a new family of hardenable steels having small quantities of several elements emerged. Specification of the composition of such alloys has become highly sophisticated with the use of computer-based alloy selection programs that facilitate specification of composition based on optimization of one or more variables such as alloy cost, physical properties, or mill processing factors. (One such program is the International Harvester Company computer alloy program called "CHAT," in which the Bureau has participated.)

During recent years substantial interest in the substitution of alloys or alloying elements has resulted from recognition that the United States is dependent on imports for many of its metallic raw materials. The Arab oil embargoes and the development of the OPEC oil price structure followed by severe shortages and high prices for metals such as cobalt and tantalum have stimulated great concern that U.S. political, military, and economic objectives could be affected adversely by external nonmarket factors. One strategy to combat such potential vulnerability, which reportedly has been pursued extensively by the Soviet Union, is to use only domestic raw materials wherever possible even though reduced service performance or higher product cost may have to be tolerated.

Alloy substitution research aimed at ameliorating the above concern departs significantly from the traditional efforts in that the goal is to develop substitutes for elements that are neither scarce nor costly but simply not produced domestically. However, the possibility that the availability of such elements might be restricted or that their price might be increased arbitrarily is not sufficient, given today's economic climate, to stimulate industrial investments in such research. Furthermore, industry will not use the results of a substitution research program unless the resulting alloy offers superior properties or lower cost. Thus, it generally has been agreed that the initiative for sponsoring alloy substitution research, if it is to be done at all, will have to come from the federal government. This might take the form of work conducted within government research facilities, contract or cooperative research at outside facilities, or the compilation and dissemination of available published information. In those cases where immediate industrial application of the results of substitution research was not practical, the data could be incorporated into an information stockpile which would be managed by an appropriate agency for utilization when needed.

An additional issue bears on the direction of alloy substitution research. Although it sometimes is justifiable to conduct research projects in a general area with the hope that the results will have such broad applicability or take such a serendipitous turn that the results will justify the effort, sponsoring organizations usually demand a clearer view of the potential usefulness of their funds. In the case of alloy substitution, the principal benefits are perceived to arise in the event of restricted availability of various mineral commodities. However, several observers have pointed out that mineral commodities are likely to be restricted for only brief periods because of the financial needs of the supplying corporations or countries. Consequently, it is possible that only during a major non-nuclear war would substitution for imported elements become a major strategic requirement. In this context, a number of short-range strategies including stockpiles, allocation, and general conservation procedures must be considered along with the longer range strategy of alloy substitution. In addition, the question is raised as to whether substitution research should cover the entire spectrum of critical element usage, should concentrate on the largest volume uses, or should restrict itself to defined essential uses. Consideration of this question is important because the field of alloy research is so broad that a program within the financial and technical resources likely to be available to the Bureau of Mines will have to be carefully targeted and directed to be effective.

CURRENT PROGRAM

The Bureau's projects on alloy substitution were reviewed during the summer of 1982. At that time, the substitution for critical and strategic materials area included 34 projects. Of these, six in-house projects and four contracts dealt with substitution for critical elements within a defined commercial alloy base. Eight other in-house projects were aimed at the development of unique coatings, claddings, or composite structures with the stated objective of reducing requirements for critical metals in industrial applications. Three additional projects were considered to fall into the category of exploratory phenomenological research, again with the goal of indentifying opportunities for alloy substitution work. The alloy substitution projects are listed in Table 1. The remaining projects are considered in the substitute raw materials chapter of this report.

The total planned expenditure for alloy substitution for fiscal 1982 at the research centers was $3.76 million. A significant portion of the Bureau's alloy substitution work represented research that had recently been reprogrammed in response to the National Materials and Minerals Policy, Research, and Development Act of 1980. Not all of it was reviewed, and a detailed project-by-project critique seemed premature. For the most part, the committee's assessment was that the problems identified were real and the project goals were technically realistic. There is a significant degree of duplication of prior and ongoing industrial work (some of which may be proprietary); however, this is quite understandable considering the short period of program preparation for the augmented and expanded portions of the reprogrammed effort. In general, the equipment available to support the work under way at the Albany Research Center was adequate. Equipment at Rolla, and possibly at the other research centers, appears to the committee to be somewhat out-dated or inadequate for this research. However, it is assumed that as the projects evolve, additional state-of-the-art equipment will be acquired or cooperative arrangements made to use non-Bureau laboratory facilities.

The committee was informed that current restrictions have made it difficult to hire engineers experienced in the alloy development field. Consequently, the research center managers have been forced to shift personnel from other research fields into the alloy development work in order to meet the new programming goals. Nevertheless, the personnel interviewed at Albany and Rolla were generally enthusiastic about their work and appeared to have acquired a creditable level of expertise in the technologies involved. Again, the committee assumes that additional staff members with pertinent experience will be hired.

TABLE 1 Alloy Substitution Research Projects

BuMines Code	Title	Research Center	Funding (thousands of dollars)
Phenomenological or Long-Range Alloy Development Projects			
S-82-MR-11	Wear of mining equipment	Spokane	20
Av-82-MR-11	Applied corrosion research	Avondale	310
RO-82-MR-15	Alloys to resist hydrogen embrittlement	Rolla	150
Alloy Substitution Projects			
AL-82-MR-19	Substitutes for critical materials in mining and processing equipment	Albany	130
AL-82-MR-16	Chromium-free and low-chromium alloys as substitutes for stainless steels	Albany	610
AL-82-MR-22	Dispersion-strengthened alloys to reduce critical materials needs	Albany	230
AL-82-MR-17	Substitutes for cobalt in cemented carbides and tool steels	Albany	415
RE-82-MR-15	Cobalt substitutes in permanent magnets	Reno	155
J0188167	Development of chromium-free constructional alloy steels	Contract	
J0295073	Chromium substitution in stainless steels	Contract	
J0295073	Potential for development of manganese-base alloys as substitutes for chromium-bearing alloys	Contract	
J0113104	Development of chromium-free construction alloys steels	Contract	
Unique Structures and Composites			
AL-82-MR-18	Wear-resistant materials for mining and mineral processing equipment	Albany	500
AL-82-MR-24	Surface alloying of iron-base castings	Albany	155
RO-82-MR-13	Chemical-vapor-deposited coatings for valve components	Rolla	155
RO-82-MR-12	Hard surfacing of steels	Rolla	165
AV-82-MR-12	Surface nitriding for corrosion protection of pump and valve components	Avondale	120
RO-82-MR-11	Improved soldering and brazing systems	Rolla	190
Miscellaneous Projects			
SL-82-MR-15	Vapor-phase productions of titanium alloy powder	Salt Lake	240
AL-82-MR-15	Improved titanium components through innovative processing technology	Albany	215

GENERAL OBSERVATIONS

As stated previously, the Bureau's present alloy substitution research represents a greatly augmented and expanded program made possible by reprogramming in response to the 1980 Act. Research work is under way in the newly programmed areas, and some interesting results already have appeared. However, before the Bureau invests much more time and money in the program, the following matters should be addressed:

1. At the time of the assessment, the Bureau had not yet developed a comprehensive strategy for alloy substitution research. The current program at that time was clearly a "grass roots" response to a fairly vague and broad directive, and the direction and probable results of some projects may not be consistent with the goal of reducing requirements for critical elements.

2. Alloy development has generally been the traditional forte of the industrial research community and, to a lesser extent, the national laboratories. Despite the current economic climate and widespread staff reductions at many industrial research facilities, an enormous amount of this type of work continues. Industrial firms generally are better able to identify problems or opportunities for new alloys and are more capable of commercializing their work directly. The institutional isolation of the Bureau laboratories from the marketplace could prove to be a major disadvantage.

3. Since both industrial and national laboratories have been active in alloy development for many years, they possess a vast body of experience, equipment, and proprietary information. The cost of duplicating even a part of these technical and intellectual assets may be beyond the resources of the Bureau of Mines. Through appropriate contract funding (as exemplified by its contract with the International Harvester Company), the Bureau could gain direct access to some of these facilities and knowledge; if it does not do so, pertinent information on alloy development is likely to be incomplete and out-dated when available at all.

4. Many believe that government involvement in any research should be restricted to supporting very long-range, high-risk projects (e.g., developing technology to extract minerals from domestic, low-grade, unconventional deposits) and to addressing national problems for which private-sector economic incentives are lacking (e.g., finding substitutes for chrominum in iron and steel). The Bureau's current alloy substitution program includes projects in areas already being addressed by industry. This is especially true in the coatings, claddings, and composites field, and continuation of the Bureau's applied research and development projects in this area should be reviewed very carefully for any duplication.

5. The Bureau has established an extensive series of cooperative agreements with industrial firms, trade associations, and other government agencies. For the most part, these agreements are in the

traditional spheres of the Bureau's activities. However, it has moved to establish new agreements in the alloy development field. In particular, the Bureau has developed ties with the American Society for Metals, with which it cosponsored a symposium at Vanderbilt University in 1982. It is essential that these ties be extended and strengthened so that the Bureau's activities will have the visibility necessary to stimulate the needed technical input from industry. The effectiveness of such interaction would be further enhanced if it were directed by an individual with considerable experience in industrial or academic alloy research and market development.

RECOMMENDATIONS

In the area of alloy substitutes the following recommendations are made:

1. The Bureau's Washington staff should establish clearly defined goals for the alloy substitution research. Based on these goals specific implementation strategies can then be developed. The foregoing should take into consideration the major substitution programs of other organizations and government agencies.

2. Equipment and manpower requirements for the next five years should be determined. The resources likely to be available to the Bureau must be reconciled with what is needed to do the job.

3. The level of funding required to support successful research in specific selected areas should be determined. The needs of the industries most familiar to the Bureau should be emphasized. The resources (equipment, personnel, etc.) needed for specific projects will vary, but current funding levels for individual projects appear to be inadequate.

4. A permanent, independent oversight committee to advise the Bureau on the currency and pertinency of its alloy research, and composed of representatives from industry and academia who are experienced in the alloy development field, should be established.

5. Consistent with federal directives and guidelines for research, the alloy substitution program should be redirected to focus on long-range activities. Work should be aimed at identifying broad alloy responses to industrially important environmental conditions. The specification of optimum alloy should be left to industry.

6. Consistent with overall funding and staff levels within the Bureau, contract research at industrial facilities with extensive capabilities in specific alloy fields should be continued.

7. Cooperative agreements with appropriate societies and industrial groups should be strengthened and expanded to provide for program visibility and to generate private-sector input.

8. The various activities of the Bureau and its personnel in areas such as joint sponsorship of symposia and workshops, committee participation, publication of reviews and data sheets, which have been effective in the past, should be continued.

9. The Bureau should increase its expertise in physical metallurgy and alloy development. This should include the hiring of personnel with industrial experience.

10. Alloy substitution work should be concentrated at one research center to facilitate project management, staff interaction, and efficient utilization of equipment. The research center at Albany, Oregon appears to be the most logical choice.

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SUBSTITUTE RAW MATERIALS

Whereas the alloy substitutes work represents a greatly augmented and expanded effort for the Bureau of Mines, the development of new processes to win metals and other products from ores has long been a significant Bureau concern and falls clearly within its historically defined responsibilities. Thus, the development of processes to utilize domestic raw materials as substitutes for imported raw materials, ore concentrates, and finished materials, reflects only redefinition of the goals of a traditional Bureau activity--as indeed is the case with the materials research work.

The general historical perspective and current strategy for substitute raw materials research is much the same as for substitute alloy development. Since these aspects of the Bureau's efforts were discussed in Chapter 2, they will not be mentioned here except to note certain differences.

The Bureau has had longstanding and close relationships with the various domestic industries involved in the mining, milling, and processing of ores and has done considerable research in mining, beneficiation, and process development to aid these industries. Despite such efforts, domestic production of many nonrenewable materials has been declining steadily, especially since World War II, and the United States now imports some 90 percent or more of 15 elements and metals and some 50 percent of 28 materials. This decline has been accelerated by several factors including extensive depletion of the domestic high-grade ores of numerous materials; high labor costs; strict environmental regulations; a slowing of industrial research, which is aimed more at improvement of existing processes than at development of new ones; and more aggressive research and operations in foreign nations, many of which extensively subsidize such efforts. As long as domestic manufacturing industries continue to utilize lowest cost materials, imports are almost certain to continue to increase despite concern about the nation's lack of self-sufficiency. Only if greater self-sufficiency were to become a primary national goal as it is in the Soviet Union would there be a turn around in the U.S. imports position.

Nevertheless, the Bureau's role in developing new processes is viewed as valid in that it is aimed at slowing, whenever possible, the increased use of imports. Unlike alloy development, which is largely the arena of private industry, the serious position in which the domestic minerals industry now finds itself virtually requires an active Bureau program designed to develop new processes to utilize domestic resources in order to keep up with foreign developments and to provide a technological base for application in conjuction with national stockpile policies in any long-term emergency.

The development of new processes can be aimed either at the use of relatively low-grade conventional ores or at the use of alternative, nonconventional resources. Both approaches can result in substitutes for imported materials, but the latter seems more appropriate for Bureau research and development since it more nearly meets the oft-mentioned criteria of long-range, high-risk research that industry is less likely to undertake in the near future. Nevertheless, current Bureau activities include process developments for both low-grade and alternative resources.

In most cases, the use of low-grade conventional resources represents only small to moderate additions to existing resources. The Duluth gabbro is an exception, however, since its successful exploitation through process improvement or new process research would greatly expand domestic reserves of nickel, cobalt, and, possibly, chromium and the platinum metals, all of which are imported to the extent of 90 percent of demand or more. Although industry could develop this resource, it is not likely to do so because of the material's low grade and resulting high cost. Thus, the Bureau has conducted an extensive program on this resource aimed at providing data to industry through technology transfer in the hope that earlier-than-anticipated exploitation might occur and significantly reducing the nation's import dependence on some or all of these critical and strategic metals.

The development of new processes for using alternative or unconventional resources in some cases can extend present conventional resources greatly. For example, successful development of processes to recover beryllium from nonpegmatitic resources and columbium (niobium) from pyrochlore increased world resources of these two metals a phenomenal hundred fold. New processes to utilize bastnaesite as well as monazite tripled rare earth resources and use of brines in addition to spodumene and other pegmatite minerals doubled lithium resources. The Bureau currently is developing a process to recover lithium from lithium-bearing clays that, if successful, again may double resources of this element. Because domestic bauxite resources are very small, the Bureau has conducted numerous development projects aimed at recovery of alumina from a number of alternative resources including clay (kaolinite), anorthosite, dawsonite, powerplant fly ash, and anthracite culm.

Such research activities are not, however, all embracing. For example, the likelihood of finding domestic conventional or alternative resources of tin is so small that no efforts beyond limited geological exploration to provide small incremental additions to a small resource base seem warranted. With existing technology the same is true for chromium. However, development of improved beneficiation methods to permit utilization of low-grade resources could greatly increase domestic chromium resources, and the Bureau already has had success with domestic laterite resources.

Although the aim of the Bureau's substitutes development program is to replace imports at least partially, it would appear that this is not a wholly justifiable goal in many cases. For example, even though the United States imports 90 percent or more of its requirements for nickel, cobalt, manganese, niobium and the platinum metals, the resources (as opposed to reserves) to demand (R/D) ratio for all of these metals is at least 40 years, which is sufficient to justify development of a substantial domestic industry in each case if costs and prices could be made more nearly competitive with imports. Because foreign ores generally are richer, it seems unlikely that new process development alone will meet this competition and economic incentives such as tax incentives, tariffs, and subsidies also will be needed if greater domestic self-sufficiency is to be achieved. Part of this analysis centers on the fact that unless the need for such policies is recognized, the nation will continue to fall increasingly behind.

CURRENT PROGRAM

In fiscal 1982, the Bureau was pursuing 10 projects (8 on aluminum and 2 on cobalt and nickel) in the substitutes for critical and strategic minerals area. In addition, a large number of other Bureau projects focus on modifying existing processes and developing new ones to use leaner conventional or alternative ores, and these activities also have, at least in part, a substitute aspect.

The 10 projects on substitute raw materials are listed in Table 2. Of these, only the two on recovery of alumina from clay by carbochlorination being carried on at the Bureau's Albany research center, which was visited by members of the committee, were reviewed with the research staff. The other 8 projects are being done at other Bureau research centers not visited this year and their review was based on reports and discussions with committee members who had visited some of these sites last year.

The bulk of the work on alumina is being carried out at Reno, Nevada and its satellite, pilot plant facility at Boulder City.* The first three projects are concerned with various aspects of the recovery of alumina from clay by leaching with hydrochloric acid. The next three

*As pointed out in the preface, several months have elapsed since the present assessment was completed. In the intervening period, the Bureau has implemented a number of changes, such as the completion of the alumina work and the closing of the Boulder City facility.

TABLE 2 Raw Materials Substitution Research

BuMines Code	Title	Research Center	Funding (thousands of dollars)
Aluminum			
BC-82-MR-3	Extraction of alumina from clay using hydrochloric acid leaching	Boulder City	175
RE-82-MR-12	Bleedstream treatment and aluminum chloride hexahydrate dissolver design	Reno	95
RE-82-MR-13	Extraction of alumina from clay by new, improved leaching techniques	Reno	240
RE-82-MR-14	Extraction of alumina from anorthosite using hydrochlorite acid leaching	Reno	85
BC-82-MR-5	Recovery of alumina from coal ash and coal shale	Boulder City	130
J0215022-RE	Extraction of alumina from anthracite culm with energy recovery	Reno/Energy Inc.	0
AL-82-MR-14	Carbochlorination of domestic clay	Albany	300
J0199151-AL	Mass spectrometric study of vapor-transport reactions in carbochlorination of clay	Albany/Colorado School of Mines	50
Nickel, Cobalt, and Platinum-Group Metals			
TC-82-MR-23	Recovery of platinum-group metals, cobalt, and nickel from Duluth Gabbro	Twin Cities	300
SL-82-MR-14	Separation and recovery of cobalt from hydrometallurgy solutions by ion exchange	Salt Lake City	205

projects are designed to determine the feasibility of applying this process to anorthosite, coal ash and coal shale, and anthracite culm. The culm project is being conducted under a subcontract with Energy, Inc., and also is concerned with the recovery of energy for process use from the residual anthracite in the culm. The work at Albany, including a subcontract with the Colorado School of Mines, is devoted to the development of an alternative process for clay using carbochlorination to produce an anhydrous aluminum chloride free of impurities.

Several projects on the recovery of alumina from nonbauxitic resources in other Bureau program areas also are in progress or have been completed. They include additional support projects at Reno and Boulder City for leaching of clay with hydrochloric acid, recovery of alumina and soda ash from dawsonite-bearing oil shales (Albany), recovery of alumina from clay by nitric acid leaching (Boulder City), fractionation of aluminum and silicon chloride mixtures (Boulder City), and two subcontract efforts.

The first of the second group of projects on substitute raw materials listed in Table 2 is concerned with filling in gaps in existing technology to permit recovery of nickel, cobalt, and the platinum metals from Duluth gabbro (Twin Cities), while the second involves use of ion exchange rather than conventional precipitation methods for the separation and recovery of cobalt from hydrometallurgy solutions. During 1981, 1982, and/or 1983 the Bureau also pursued six additional process development projects on nickel, five on cobalt, two on platinum metals, six on chromium, and one or more on most other critical and strategic elements. Finally, the Bureau has working agreements with a large number of mineral companies, mineral industry associations, and universities designed to identify problems and areas where Bureau research may be needed, to facilitate the transfer of Bureau-developed technology to industry and to promote cooperative, process test demonstrations within industry.

Because so much of the current substitute raw materials effort is devoted to development of new processes for recovering alumina from nonbauxitic domestic raw materials, it seems appropriate to review this Bureau activity over a longer time frame in order to show how projects become initiated and how incentives and goals can change as the overall problems and conditions change with time. In the wake of the Arab oil embargo of 1972-73 and OPEC's success in bringing about very large increases in oil prices, there was considerable concern that other cartels would be formed for nonrenewable materials in which the United States is resource-poor. This was particularly true in the case of bauxite resources, which occur predominantly in tropical developing countries. In response, the Bureau became actively engaged in a number of projects aimed at providing processes (most employing acid-leaching methods) for utilizing alternative domestic aluminum resources such as clay.

Attempts to form a bauxite cartel failed, however, and Australia, a friendly and reliable source of imports, continued to be the world's leading bauxite producer with the world's second largest resource (18 percent), surpassed only by Guinea with 22 percent. Discovery of bauxite resources, already with an R/D ratio of 470 years (compared to 8 for the United States), continued to increase, and the world and domestic aluminum industries showed little interest in shifting away from bauxite; in fact, it became increasingly apparent that the domestic industry was very unlikely to invest in new alumina production facilities of any kind. Thus, the development of nonbauxitic processes seemed increasingly less necessary. Nevertheless, by fiscal 1981, 1982, and 1983, the Bureau had 17 projects, including subcontracts, in progress.

Based on committee observation, the traditional Bayer process for bauxite is so simple, efficient, and economic that it seems very unlikely to be replaced by more complex acid-leaching processes. By its own admission, the Bureau concedes that these acid processes are fraught with difficulties, which is probably the main reason for the proliferation of projects, many of which were established to work out various process shortcomings. In recognition of these facts, the Bureau now is concluding most of its efforts in this area. It now seems that the only advantages of using domestic nonbauxite resources would be to marginally improve the nation's balance-of-payment position and to assure an aluminum supply in the event of a war of such duration as to completely deplete aluminum resources and materials in the national stockpile.

GENERAL OBSERVATIONS

This section summarizes the committee's general observations on the Bureau's raw materials substitution research and development program. Specific recommendations on ongoing and future efforts are covered in the last section of this chapter. Insofar as possible, these comments have attempted to answer questions posed on page 3 of the 1982 committee report, "Assessment of Mineral Resources Technology Program of the U.S. Bureau of Mines" (NMAB-399).

1. The current list of projects in the raw materials part of the Bureau's program for substitutes for critical and strategic minerals appears incomplete since many of the Bureau's other process development activities fall well within the definition of substitutes, as is quite evident from a perusal of the various project descriptions in Appendix A of NMAB 410-3. The present list appears to overemphasize alumina, which involves 13 separate projects versus a maximum of 6 for any other element. It is suggested that a further subdivision into processes for low-grade, conventional ores and processes for alternative, unconventional resources may be helpful, since work in the former area focuses largely on existing-process improvements and in the latter, mainly on the development of new processes.

2. Using this expanded definition, the Bureau's projects appear to represent a reasonably balanced effort among the various critical and strategic minerals (except for alumina) and between industry needs and governmental strategic concerns. The committee agrees with the Bureau's recent de-emphasis of its efforts on alumina and recommends that the freeing up of manpower and funds by such de-emphasis be redirected to increased efforts on the "ultramafic" metals, chromium, nickel, cobalt, and the platinum metals and significantly increased activity on manganese, which is an indispensible ingredient in steelmaking. The bulk of resources and production of most of these elements is in southern Africa and the Soviet Union, both potentially unreliable import sources.

3. Since the plight of the domestic minerals industry has considerably worsened since the committee's overall review (NMAB-399) in 1981, it heartily re-endorses its suggestion (p. 14) that the Bureau's efforts on new process development be significantly expanded. In particular, since many of the minerals companies have reduced their research staffs, this would be an excellent time for the Bureau to augment its professional staff with well trained scientists and engineers if manpower ceilings could be lifted.

4. It will be very difficult to improve existing processes or to develop new ones that can compete economically with imports of many materials because foreign resources now are generally better and richer, foreign technology and facilities are often superior, labor costs are lower, and environmental regulations are less severe. Thus, process developments would have to be supplemented with economic incentives for industry such as easier tax write-offs. In addition, improved self-sufficiency should depend on greater attention to strategic considerations by government since economic forces alone will result only in increasing imports. Despite these problems, an active research program by the Bureau is imperative to keep such problems from becoming even worse.

5. Some increase in basic research efforts appears warranted under the long-range, high-risk process selection criteria because this is probably the best way for the United States to make quantum leaps in technology a decade or more away and to stay in competition with other nations. This type effort (e.g., thermochemistry at Albany) can be done in-house where personnel and facilities are available and adequate, but much of it should be subcontracted to universities where most of the latest scientific discoveries and innovations are being made.

6. At the other end of the process development spectrum, the Bureau, in cooperation with the national laboratories, could consider becoming involved to a greater extent in the pilot planting of new processes. Given the current economic condition of the mineral industries, it is becoming increasingly less likely that industry will undertake such work. Thus, if such work is to be done at all, the Bureau must take the

lead. It is hard to sell new processes without a pilot plant demonstration. Similar efforts are being supported by foreign governments, and unless the U.S. government supports such activities the nation will undoubtedly fall further behind in demonstrated new technology.

7. The committee was briefed by Washington Bureau staff on a new programmatic decisionmaking process that includes a new method of selecting projects for study. This new method appears quite superior to older ones but only time and experience will really prove its worth. It has many commonalities with Delphi processes that have been quite successful in addressing and evaluating other types of activities.

RECOMMENDATIONS

This final section of the report lists several specific examples of areas in which the Bureau might change the direction of existing programs and/or undertake new initiatives in the development of processes for domestic raw materials in order to increase self-sufficiency in nonrenewable materials by reducing imports. The committee recommends the following actions in this area:

1. As noted earlier, the Bureau is now phasing out much of its work on nonbauxitic raw materials as domestic sources of aluminum. It is suggested that consideration be given to initiating a limited effort on the basic chemistry of the Al-Si-Fe-(O) system that later would be applicable to any of the alternative resources.

2. Seafloor manganese nodules represent a large potential source of several elements; their exploitation awaits the development of economical mining methods. Industry's chief concern with these nodules is as a resource of copper, nickel, and cobalt. Since this resource also contains very large amounts of manganese, significant quantities of iron, lead, and zinc, and lesser amounts of other elements, the Bureau should consider any necessary research and development techniques for recovering these additional metals as a means of lowering the cost of recovery of all products and coproducts. (It is also significant that the bulk of world manganese resources are in the Soviet Union and South Africa.)

3. Efforts on the "ultramafic" elements (Cr, Ni, Co, Pt) are devoted to the use of West Coast lateritic deposits, the Stillwater complex in Montana, the Duluth gabbros, and several Alaskan resources. It is recommended that such efforts be given high priority, culminating in appropriate exploratory research on the most promising of the common ultramafic rocks that are abundant in both the western coastal ranges and the Appalachians. This is a long-range, high-risk opportunity with an enormous payoff, if successful.

4. The nation's potash resources, which are essential to agriculture, are only moderate. A future resource is in solar salt bitterns but this resource falls far short of meeting domestic demands.

There are large potassium resources in leucite and enormous ones in potassium feldspars that the Bureau might evaluate. The latter is also a potential resource of aluminum.

5. As much as one third of the P_2O_5 content of phosphate rock is lost during the production of phosphatic fertilizers. In view of the fact that phosphate is an absolutely necessary, nonsubstitutable material for agriculture, and although the United States currently exports phosphate, the Bureau should examine means of significantly increasing yields. Florida phosphate rock also contains significant quantities of heavy minerals (ilmenite, rutile, zircon, monazite, sillimanite, etc.) that are now discarded, and their recovery is also an area that the Bureau might examine.

6. By-product elements, mainly of the nonferrous metals, will seldom be recovered in their own right. It is recommended that the Bureau intensify its efforts leading to maximizing their recovery, especially by *in situ* leaching which is becoming a major mining method. Very large future demands for these elements are likely to develop. Examples include large future requirements for selenium as a trace metal additive in agriculture, and gallium arsenide as photoelectric devices in solar power satellites and as semiconductors in very high speed computers. The Bureau, in conjunction with other agencies such as the Federal Emergency Management Agency (FEMA), should also evaluate the possibility and cost of establishing an economic stockpile of such elements; estimates indicate that, excluding the precious metals, the cost would be no more than a few percent of the value of the base metals.

7. Solar salt bitterns also appear to be a potential resource of boron, lithium, strontium, rubidium, and iodine. It is recommended that the Bureau evaluate the recovery of multiple products from this source especially since imports account for 100 percent of strontium demand and 90 percent of iodine needs.

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15. Supplementary Notes

16. Abstracts This report presents assessments of the efforts of the Bureau of Mines in two areas of its mineral resources technology program: alloy substitutes research, which deals with substitution of plentiful domestically available metals for improted strategic or critical metals, and minerals substitutes research, which deals with the development of strategic or critical mineral supplies from nontraditional domestic sources. Conclusions are presented and recommendations made on the need for establishing clearly defined goals, identifying equipment and manpower needs, determining optimum levels of support, redirecting programs to more long-range activities, continuing contract research, expanding cooperative agreements, continuing joint sponsorship of symposia and workshops, increasing levels of expertise in alloy development, and concentrating alloy substitution work at a single research center. Increased Bureau efforts concerning improved recovery of nonferrous metal by-product elements, potential recovery of additional elements from seafloor nodules, alternative potash resources, improved recovery of P_2O_5 from phosphate rock, and recovery of additional materials from solar salt bitterns are also recommended.

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17c. COSATI Field/Group

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