TECHNICAL REPORT: ADEQUACY OF U.S. BERYLLIUM INDUSTRIAL BASE TO MEET DEFENSE REQUIREMENTS

MAY 14, 2004

This report was produced for the Under Secretary of Defense (Acquisition, Technology, & Logistics) by the Deputy Under Secretary of Defense (Industrial Policy) from March 2003 - March 2004. Support was provided by the Institute for Defense Analyses (IDA).

TECHNICAL REPORT:
ADEQUACY OF U.S. BERYLLIUM INDUSTRIAL BASE TO MEET DEFENSE REQUIREMENTS

PREPARED BY
OFFICE OF THE DEPUTY UNDER SECRETARY OF DEFENSE
(INDUSTRIAL POLICY)

MAY 14, 2004

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Executive Summary

Overview

The U.S. lost its only capability to manufacture primary beryllium metal in October 2000 when Brush-Wellman, Inc. (BWI) mothballed its beryllium reduction facility for economic reasons. Since then, BWI has relied on a dwindling supply of ingots from the National Defense Stockpile of Strategic and Critical Materials (NDS) in the Defense Logistics Agency (DLA) to meet defense and other needs for high purity beryllium metal products for its U.S. and international customers. BWI's foreign supplier in Kazakhstan cannot currently meet the purity levels required for these high purity beryllium products although imports can be employed in production of a lower purity metal matrix composite with some defense applications.

The projected depletion of domestic supplies of high purity beryllium metal is important because beryllium is a strategic and critical material under the administration of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 *et seq.*) and is used primarily for defense-related products ranging from aircraft to satellites to nuclear warheads. Because of beryllium's unique properties, including light weight combined with extraordinary strength and stiffness, it has few if any substitutes in some of its most critical strategic and tactical applications including those essential for transformational warfare.

Because of the projected depletion of beryllium metal supplies, Congress has directed the Department of Defense (DoD) to conduct a study of the beryllium industrial base and to submit a report on the results of the study to Congress. This document includes findings and recommendations and more detailed results of the study.

The study focuses on two issues involving the beryllium industrial base. First, in the short run or transition period, when will current U.S.-based supplies from NDS be depleted and can this date be extended by alternative supply and distribution policies? Second, what is the best long-term solution to providing the United States with supplies of the material? To estimate depletion of NDS inventories, the study employs a supply depletion model which can vary supply and demand assumptions.

The study concludes that the depletion date for domestic NDS beryllium metal supplies, based on an assumed annual growth rate in demand of six percent over at least the next five to six years, could be extended from a projected date of 2008 until 2011 if secure imports of beryllium metal have quality levels sufficient for low purity applications. The depletion date could then be extended for a few more years by gradual release of NDS hot pressed powder billets currently held in reserve, once the NDS ingot inventory is exhausted.

Longer term, the feasibility of a new, more efficient and occupationally safer production process for primary beryllium is now being explored. While it may be three years before the complete results of that project are known, BWI has conducted preliminary

R&D work. Given some Federal Government R&D funding for which it has applied, the firm expects to know within a year whether a new manufacturing technology is feasible. However, it could take three to five years to design, permit, construct, equip and test a new primary beryllium facility regardless of whether current or new manufacturing technology is employed. Therefore, it is important that the depletion of NDS inventories be carefully monitored by the DoD so that policy decisions to ensure a new source of beryllium metal supply leave enough lead time to avoid a shortage of feedstock for beryllium metal needed for defense-related applications.

RECOMMENDATIONS

Even if the quality levels of imported beryllium material from Kazakhstan reach acceptable levels for high purity applications in the next three years (while the feasibility of new beryllium manufacturing technology is being evaluated), the risks of a sole dependence on Russia for beryllium feedstock and Kazakhstan for beryllium ingots (with China as the only unlikely back-up) are too great for a material that is strategic and critical for systems required to meet DoD transformational and strategic warfare objectives.

Moreover, if the DoD were to authorize BWI to transfer its beryllium manufacturing technology to Kazakhstan to improve the quality of imports, there would be additional risks. The U.S. would have no control over sales of very high purity beryllium metal or its manufacturing technology to third countries that produce or seek to produce nuclear weapons or defense-related products essential to transformational warfare.

Since imports are not a viable long-term option due to purity level limitations and commercial investment alone is highly unlikely, the DoD should begin multi-year funding of $30 to $45 million (i.e., $6-9 million/year) in a cost share program with private industry, possibly through Title III of the Defense Production Act, to support the design, construction, and equipping of a new domestic primary beryllium facility incorporating to the maximum extent possible new manufacturing technology.[1] In the meantime, incremental R&D funding not to exceed $5 million could determine if new, more efficient and occupationally safer beryllium manufacturing technology could be employed in a new production facility.

In addition, high purity NDS reserves of hot pressed powder billet should only be released as a last resort, serving as a hedge against delays in bringing the new facility on line.

[1] This report does not constitute a formal request for budget authority or appropriations to implement its recommendations.

FINDINGS AND RECOMMENDATIONS

BACKGROUND AND APPROACH

The U.S. lost its only capability to manufacture primary beryllium metal in October, 2000 when Brush-Wellman, Inc. (BWI) mothballed its beryllium reduction facility for economic reasons. Since then, to meet defense and other needs for high purity beryllium metal products, BWI has relied on a dwindling supply of beryllium ingots from the National Defense Stockpile of Strategic and Critical Materials (NDS) in the Defense Logistics Agency (DLA) for which it has contracted. BWI's foreign supplier in Kazakhstan currently cannot meet the purity levels required for these high purity beryllium products.

Because of the diminishing supply of domestic beryllium feedstock, the Congress in section 824 of Public Law 108-12, the National Defense Authorization Act for Fiscal Year 2004, directed the Secretary of Defense to conduct a study of the adequacy of the U.S. industrial base to meet defense requirements of the United States for beryllium. The Secretary was directed to submit to Congress by March 30, 2005 a report on the results of the study including discussion of issues relating to beryllium supply, the need for modernization of the primary sources of beryllium, and the advisability of meeting future defense requirements and maintaining a stable domestic industrial base of beryllium sources through public-private partnerships, administration of the National Defense Stockpile and any other means the Secretary finds feasible.

This Introduction covers the findings and recommendations of the study and it is followed by chapters that outline the detailed results of the study. The study was initiated by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) in consultation with the Department of Energy prior to the drafting of the Congressional report requirement. Within the guidelines of the Congressional mandate, the study explores two issues; how soon are the NDS inventories of beryllium likely to be depleted and what are the short and long-term options for the U.S. to meet future requirements for beryllium metal.

The projected depletion of domestic supplies of beryllium metal is important because beryllium is a strategic and critical material under the administration of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 *et seq.*) and is used primarily for defense-related products ranging from aircraft to satellites to nuclear warheads. Because of beryllium's unique properties, including light weight combined with extraordinary strength and stiffness, it has few if any substitutes in some of its most critical strategic and tactical applications including those essential for transformational warfare.

To support the analysis which estimates the date when high purity beryllium metal will no longer be available to meet U.S. and international needs, the study includes a model to simulate the use of available supplies to meet future demands. In particular, this so-called depletion analysis model calculates how long U.S. and allied beryllium consumption requirements can be met based on alternative assumptions about interim beryllium supplies and requirements. The simulations show how the length of this interim supply period would be affected by potential foreign supplies, alternative schemes for releasing uncommitted NDS inventories, and various demand scenarios.

To help ensure the projections from the depletion model are reliable, the text provides extensive background information on factors that affect supply and demand for beryllium through 2020. On the demand side, the text presents an extensive list of present and potential future applications of beryllium, analyzes consumption trend lines, notes current demand and estimates likely consumption growth rates based on discussions with key Department of Defense (DoD) program offices about their expected use of beryllium and discussions with BWI about what its customers are planning.

Finally, based on the detailed supply and demand data the study presents policy options to support recommendations for both distribution policy for NDS beryllium inventories in the short run and a long run solution to the beryllium supply issue.

BERYLLIUM SUPPLY ISSUES

The form of beryllium which is the focus of industrial base concern is primary beryllium which serves as the feedstock for both high purity beryllium metal and a metal matrix composite, AlBeMet, which has much lower purity constraints for beryllium. Both of these metal products are employed in the production of defense-related components.[2]

There are three producers of primary beryllium in the world. The one U.S. supplier, BWI, is an integrated producer that mines and processes ore in Utah and currently produces beryllium metal products in Ohio from a combination of NDS beryllium metal ingots which it has acquired and from scrap. Beryllium metal production generates a very high percentage of scrap both at BWI and among the machining shops that make parts. BWI collects much of this scrap and recycles that portion which, when mixed with higher purity feedstock, meets minimum purity levels for use in the generation of new beryllium metal. Once NDS inventories are depleted, BWI must find another source of high purity beryllium feedstock to mix with scrap. Potential sources are imports or a new production facility for primary beryllium.

The second producer is Ulba Metallurgical Plant in Kazakhstan. Ulba produces beryllium metal from beryllium ore supplied by Russia. BWI signed a contract with Ulba in September 2003 to acquire 25,000 pounds of vacuum cast beryllium ingot annually for ten years contingent on the material meeting minimum purity requirements that would allow for its use at least in production of the lower purity AlBeMet. So far BWI's

[2] The availability of reliable supplies of ore-containing beryllium is not an issue since the domestic producer, BWI, has proven reserves in Utah that should last at least 75 years as well as additional unproven reserves. Beryllium-copper master alloy, the form of beryllium accounting for most domestic consumption because of its extensive use in applications such as consumer electronics and telecommunications, is produced without going through the primary beryllium production process and therefore is not a concern of the present study.

tests of sample Ulba material indicate that with normal remelting the material cannot achieve purity levels required for use in production of the high purity beryllium metal. Therefore, at this time Ulba cannot be a source of feedstock for the beryllium metal employed in most defense applications. However, since the lower purity AlBeMet now accounts for 40 percent of beryllium metal consumption, the availability of imports for production of AlBeMet will definitely extend the depletion date of the remaining NDS ingot feedstock.

China also produces beryllium metal but BWI has concluded based on plant visits that its purity level is also significantly below Western standards. Moreover, it is mostly consumed for internal use in military and other programs.

Despite its high price relative to other metals and the occupational health and safety issues involved in its manufacture and machining, beryllium has been employed in a changing but persistent set of defense applications ever since World War II. Currently, defense consumption including international sales accounts for roughly 85 percent of total demand for beryllium metal as distinct from other forms of beryllium such as beryllium-copper alloy. The key to its defense demand is a unique set of physical and mechanical properties including light weight, stiffness, strength, high melting point, quick heat absorption and dissipation, and high reflectivity to infrared wavelengths. These properties make beryllium metal attractive in many aerospace applications where structural integrity and light weight is important and in sensor-related applications where resistance to vibration is essential for structural parts or the sensor itself is based on the infrared spectrum. Because of beryllium's unique nuclear properties, it is also very useful in nuclear reactors and warheads.

After a period of decline in beryllium demand in the 1990s associated with reduced defense procurements and the termination in production of nuclear weapons, total demand for beryllium metal including international sales has grown during the 2000-2003 period at a rate of six percent per year, reaching a total of roughly 35,000 pounds in 2003.[3] Discussions with DoD program offices and BWI suggest that demand will continue to grow at or over an average rate of six percent annually for the next five years based largely on increased applications in optics and other sensor systems, satellites and avionics. Beyond 2009, growth in demand is less certain but the cyclical consumption pattern in specialty metals suggest that at some point demand for beryllium may stabilize or decline. For example, cancellation of one or two major aircraft programs could eliminate growth for defense purposes altogether but leave a substantial requirement for the metal at or near 40,000 pounds per year for legacy programs and ongoing requirements.

Moreover, certain Department Of Energy (DOE) contingencies that are defense-related but unpredictable could generate large immediate requirements for beryllium metal. For example, the nuclear weapons surveillance process could uncover unexpected

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[3] In this Report, quantities of beryllium consumed are based on the beryllium metal content of shipments rather than the gross weight of beryllium containing material delivered which would vary between beryllium metal and AlBeMet.

deterioration due to aging or other problems. However, while an emergency could generate a large total requirement for beryllium within the DOE weapons program, DOE's annual consumption would be limited by the manufacturing lead times for the weapons components and subsystems.

The most likely supply-demand scenario for the entire period between 2004 and 2020 is that annual imports of 25,000 pounds of beryllium ingot from Kazakhstan will be available for use in low purity beryllium products for most or all of that period and that beryllium metal demand will continue to grow at an average rate of six percent a year for roughly the next five years (2004-2009) and then level off or decline.[4] However, even assuming a more adverse demand scenario of six percent growth for the entire period, Figure F-1 indicates that the U.S. would have between seven and eleven years before beryllium supply depletion, depending on availability of imports and distribution policy for release of DLA reserves of billet after its supplies of ingot are exhausted.

FIGURE F-1: PROJECTED BERYLLIUM SUPPLY DEPLETION DATES

SCENARIO	ESTIMATED DEPLETION DATE
• Imports of 25,000 lbs annually available to U.S. producer for entire period but no reserves of NDS billets are released for sale	July 2011
• Imports not available to U.S. producer at all, but 70 percent of NDS billet reserves released for sale when inventories of NDS ingots are exhausted	April 2012
• Imports of 25,000 lbs annually available to U.S. producer and 70 percent of NDS billets released for sale when inventories of NDS ingots are exhausted	October 2015

Source: Institute for Defense Analyses

This range of most likely supply depletion dates (2011-2015) should be sufficient to resolve the long term supply problem. Under our recommended policy proposals involving the building of a new, more efficient, domestic production facility, we estimate three to five years for design, permitting (including environmental reviews), construction, and testing of a new production facility. Since R&D on the feasibility of more efficient manufacturing technology is likely to take at least three years, a portion of the remaining

[4] A recent reassessment of the rate at which BWI is consuming NDS beryllium ingots in its production process indicates that it is using them at a significantly faster rate than projected for 2004 and that this is likely to continue through 2005. Apart from some unanticipated sales, the increase in consumption rate of ingot appears to be due to a temporary increase in the metal to scrap ratio in the production process because of a temporary shortage of scrap and the unique properties of the beryllium being produced for the Webb Telescope. However, the increased burn rate for NDS ingot in the short run is not expected to significantly affect the long term projections for supply depletion in this report since recent feedback from some Federal Government program offices indicates the increased burn rate will be partially offset by reduced projections of beryllium consumption over the next five years in some other programs.

NDS billet reserves could be released for sale to cover any shortfalls between the start of construction and a new plant coming on-line.

POLICY OPTIONS AND RECOMMENDATIONS

We have considered three broad approaches to the beryllium metal supply problem: (1) authorize BWI to transfer beryllium manufacturing technology to the Kazakhstan producer to increase the purity levels of the Ulba product and then depend exclusively on foreign supplies, accompanied by a larger domestic beryllium inventory in the National Defense Stockpile; (2) rely on a crash R&D program to find replacements for high purity beryllium metal in defense applications; or (3) authorize a Federal Government cost share program with private industry, possibly through Title III of the Defense Production Act, for the design, construction and equipping of a new domestic production facility as well as provision of R&D funding to assess the feasibility of a more efficient production technology.

FOREIGN DEPENDENCE BASED ON TRANSFER OF MANUFACTURING CAPABILITIES

The first option, technology transfer followed by total dependence on a single source of imports, is unattractive for several reasons. To be sure, the U.S. is dependent primarily on imports for the feedstock for some other strategic materials such as cobalt and chromium which have had multiple reliable foreign sources for decades. However, placing the U.S. in a situation where the nation is totally dependent on beryllium metal ingots from Kazakhstan (with China as an unlikely back-up) poses serious risks, given the material's criticality in many strategic and tactical programs.

First, it would be natural for Ulba to aspire to sell more advanced products than vacuum-cast ingots in order to receive the benefits of the greater value-added. There could come a time when Ulba would displace BWI as the producer of downstream products, perhaps by halting ingot sales to BWI. In that case, the U.S. would be dependent on Kazakhstan alone for all beryllium products. Second, sole dependence on Kazakhstan for beryllium metal ingot, or eventually all beryllium products, would be a double dependence because the Ulba plant is dependent on Russia for beryllium feedstock. Third, the Ulba facility parent company is owned by the Kazakhstan Government. Government ownership enhances the risks that supply could be disrupted in the future for political reasons. Fourth, the only other producer is China and BWI has concluded based on visits to the Chinese facility that its beryllium metal purity is even lower than Kazakhstan's, to say nothing of China's reliability in the long run as a supplier of adequate quantities of such a critical defense material.

Apart from sole source dependence issues, the transfer of manufacturing capability has other risks and costs. The U.S. would have very little control over the diffusion to third parties of very high purity beryllium metal or the manufacturing technology to produce it once the manufacturing technology were transferred. Since beryllium is used in nuclear weapons, this risk involves WMD proliferation issues as well as other national security threats to the U.S. Moreover, the foreign dependence option would have significant financial costs to the Federal Government because it would be prudent to accompany it with a NDS acquisition of five years' projected consumption of beryllium and an upgrade of some of that beryllium to billet form for the Stockpile. The combined dollar value of that acquisition and upgrade could reach $45 million, making the alternative option of a new domestic plant (at $40-45 million) particularly compelling.

Crash R&D Program for Beryllium Substitutes

A second option would be for DoD, perhaps in cooperation with some other Federal agencies, to rely primarily on a crash program to find substitutes for beryllium in defense and essential civilian applications to deal with anticipated shortfalls but also because of the material's occupational health and safety risks primarily during manufacturing and machining. The Missile Defense Agency is already funding several beryllium replacement R&D projects for its programs. However, this option pursued alone is highly risky when generalized for all national security applications. The number of critical defense applications is considerable and the likelihood that an R&D program could find adequate substitutes for all of them in the probable timeframe for supply depletion is dubious. Because of its costs relative to other metals and occupational safety risks, beryllium has long been a target for substitutes. Yet its essential applications persist because of its unique properties. Moreover, the aggregate costs of such an R&D program, to include requalifying scores of subsystems that currently employ beryllium, may well exceed the total cost of a new domestic plant.

Federal Cost Share for New Production Facility

Given the risks and costs associated with the other options, a DoD cost share program with private industry to build a new domestic production facility is the most attractive alternative. BWI has noted that although its sales of beryllium metal are now profitable at the divisional level, continued sales of beryllium in the expected $30 to $40 million range at operating profits of $5–6 million per year will not be sufficient for its parent company, Brush Engineered Materials (BEM), to fund a new primary metal plant. Hence, the Government would have to cost share such a facility. This financial assessment is realistic based on the parent firm's recent performance.

Government financial support for a new production facility involves a two-step process. First, an incremental R&D effort not to exceed $5 million could determine whether the potentially more cost-effective and occupationally safer electrolytic de-oxidation (EDO) manufacturing technology (or some other newer technology) is feasible for beryllium. The EDO process could provide important advantages including significantly lower construction and operating costs. Industry should be challenged to complete the R&D in three years to allow for design, permitting, and construction of a new facility in a faster timeframe than projected depletion of current feedstocks.

Second, pending initial findings from the aforementioned R&D effort, the DoD should prepare to initiate a multi-year program of $30 to $45 million ($6 to 9 million/year) in a cost share arrangement with private industry, possibly through Title III of the Defense Production Act, for new domestic production capacity based on the best available manufacturing technology. It is unlikely that private sector investment will occur without Government cost sharing. The first year of funding should be for initial plant designs while the R&D on manufacturing technology is proceeding.[5] If the EDO technology is feasible, construction and equipment costs could be significantly less than $45 million.

TRANSITION PERIOD

There are two key factors that could affect the length of the transition period until current feedstock of high purity beryllium from NDS ingots is depleted—the reliability of imports for at least non-high purity applications and future demand for beryllium over the next five to seven years. If NDS ingot is about to be exhausted before a new facility comes on line, the depletion date of beryllium feedstock should be delayed by authorizing DoD to release for sale some of the NDS reserves of the high purity billets current held for DOE and DoD emergencies. There is sufficient NDS billet to meet likely DoD and even emergency DOE needs on an annual basis for several years. However, DOE staffers have rightly expressed concern that the NDS billet inventories ideally should not be used unless a new plant has completed the permitting stage and is within a year or two of coming on-line.

Even if some NDS billet must be released, a prudent reserve of the billets should be maintained, at least initially, sufficient to meet potential DOE contingencies. The prudent reserve that would not be offered for sale initially would be based on DOE's likely ability to consume beryllium during a period starting with identification of an emergency and ending with the establishment of U.S. access to newly produced beryllium metal.

[5] This report does not constitute a formal request for budget authority or appropriations to implement its recommendations.

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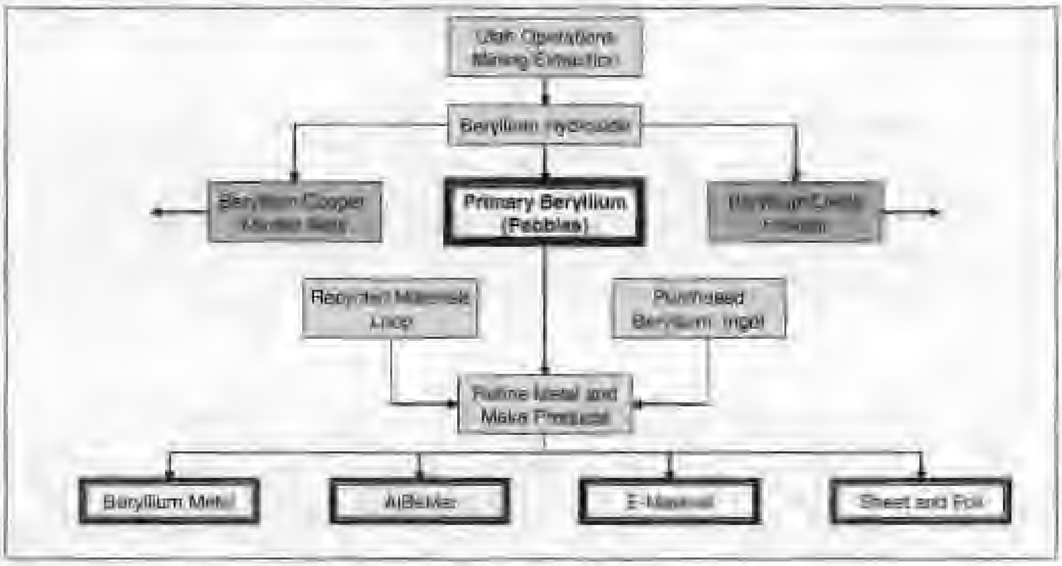
CHAPTER ONE: BERYLLIUM SUPPLY

This chapter assesses the future supply of beryllium metal including the various forms of the material, the current producers worldwide, sources of ore as basic feedstock, the production process for beryllium metal including the vital role of scrap, potential new production technology, and the status of Federal Government inventories in the National Defense Stockpile (NDS).

THE BERYLLIUM METAL INDUSTRY

Primary beryllium is a raw, intermediate form of the metal that must be further refined and processed. This study focuses on those forms of beryllium metal that are derived from primary beryllium. The manufacturing process for primary beryllium is illustrated on Figure 1-1. Beryllium hydroxide, derived mainly from bertrandite ore mined in Utah by Brush Wellman Inc., (BWI) is the basic feedstock used to produce primary beryllium.

FIGURE 1-1: MANUFACTURING PROCESS FOR PRIMARY BERYLLIUM



Source: Institute for Defense Analyses

at the firm's Elmore, Ohio plant.[6] Some important BWI products primarily for commercial markets, such as beryllium-copper master alloy and beryllium oxide, also depend on the hydroxide feedstock but bypass the primary beryllium production process. However, as depicted at the bottom of the chart, there are a number of materials with a high beryllium content that depend on a feedstock of primary beryllium or products already refined from primary beryllium such as purchased ingots or scrap. Of the four listed, this study focuses on high purity beryllium metal and AlBeMet since the amount of E-material produced is small relative to the output of pure beryllium metal and AlBeMet. Sheet and foil forms represent further processing of the other types of beryllium metal.

Pure beryllium metal is a highly refined product used for applications with demanding performance specifications. It is available in a variety of structural, instrument, and optical grades that vary in purity level, composition of trace elements, and other characteristics.[7] Beryllium content for the pure metal is roughly 99 percent or even higher for some grades. Conversely, AlBeMet is an increasingly popular metal matrix composite (with only 62 percent beryllium) that offers many of the advantages of pure beryllium metal in combination with the lower cost and the fabrication advantages of aluminum.[8] This lower beryllium content allows the use of less pure beryllium inputs in its production.

U.S. Producers

Until BWI mothballed its facility that produced beryllium metal in October 2000, it was the sole U.S. producer of primary beryllium. Globally, there are only two other producers, located in Kazakhstan and China.[9] BWI is an integrated producer that mines and processes ore in Utah, produces beryllium metal in Ohio, and distributes products through facilities in the U.S., Europe and Asia. The firm has worked closely with the government, operating a government-owned plant in Luckey, Ohio, from 1949 to 1958

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[6] The availability of reliable supplies of beryllium-containing ore is not a problem for domestic or dependable foreign production of beryllium metal. BWI mine bertrandite ore in the Topaz-Spor Mountain area of Utah and converts it into beryllium hydroxide concentrate at its Delta, Utah, extraction facility. Proven reserves in Utah are estimated at 18,000 metric tons (of contained beryllium). See *U.S. Geological Survey, Mineral Commodity Summaries 2003*, January 2003. BWI estimates, based on recent average production levels, that these proven reserves will last at least 75 years and it has identified probably but unproven reserves amounting to about 50 percent of its proven reserves. See Brush Engineered Material, Inc., "2002 Annual Report," 20-21. Further, substantial unexploited reserves of other beryllium-containing ores are located in the Seward Peninsula of Alaska and at Yellowknife in Canada's Northwest Territory. The Yellowknife property, located at Thor Lake, is owned by Beta Mineral, Inc., which considers the deposit to be world class and claimed in 2002 to be seeking permitting to enable mine development. See www.betaminerals.com. Overseas, beryl ore production capacity is concentrated in Russia and China, with additional deposits in Brazil and elsewhere.

[7] The various grades of pure beryllium metal which have different properties suiting them for different applications. The differences in grades have blurred somewhat over time.

[8] Other companies have produced similar beryllium-aluminum products under different names.

[9] Imports of beryllium for national defense purposes are not restricted by the Berry Amendment (10 U.S.C.2533a).

and also providing materials for the NDS over the years. For a number of years, BWI has been virtually the only Western supplier of beryllium metal.

BWI is a wholly owned subsidiary of Brush Engineered Materials (BEM), which had losses of $13 million on 2003 sales of $401 million. Overall, the parent company has been profitable for only two of the last five years.[10] The Beryllium Products Group, the smallest operating group of Brush, produces pure beryllium metal, E-material, and AlBeMet, and accounted for only 8.8 percent of overall sales in 2003. The Alloy Products Group, whose products include beryllium-copper, accounts for over 40 percent of sales. Figure 1-2 below illustrates the 2003 revenues and operating losses by business segments:

FIGURE 1-2: BRUSH ENGINEERED MATERIALS 2003 SALES, EBIT BY SEGMENTS, AND NET INCOME

	Metal Systems	Micro-Electronics	Other	Total
Revenues ($M)	239.4	157.3	4.3	401.0
EBIT* ($M)	(16.6)	(12.6)	(5.4)	(9.3)
Net Income (loss)				(13.2)

* EBIT = earnings before interest and taxes

Source: 2003 Brush Engineered Materials Annual Report

BWI acknowledges that the Beryllium Products Group made a modest operating profit in 1999 after several years in the red and by 2003 achieved operating profits of $5.6 million on sales of $35.2 million. Yet the Metal Systems segment as a whole lost over $16 million in 2003. The parent firm notes that, even assuming continued annual sales of $30 to $40 million by the Beryllium Products Group for the foreseeable future, BEM could not justify an investment of roughly $50 to $70 million in a new primary beryllium facility without a cost share with the Federal Government. This assessment is realistic given the parent firm's recent financial performance, shown above at the corporate and segment levels.

KAZAKH PRODUCER

The Ulba Metallurgical Plant in Kazakhstan was the major Soviet supplier of beryllium. Because of this history and location, Ulba has close ties with other producers in the former Soviet Union (FSU). Ulba's parent, with 90 percent ownership, is Kazatomprom, which in turn is owned 100 percent by the Kazakhstan government. For beryllium, Ulba depends on Russian ores and markets and has formed a marketing joint venture with

[10] 2003 Annual Report.

the Moscow Nonferrous Metals Processing Plant.[11] Therefore, any dependence on Kazakhstan beryllium is a double dependence on that country and Russia. Moreover, Ulba's main business is the production of uranium-based fuel for nuclear power plants. In that business, Ulba mines uranium and produces nuclear fuel but depends on Russia for uranium enrichment. The Russian nuclear conglomerate TVEL has shown a continuing interest in close cooperation with Ulba.[12]

After the Cold War, Ulba entered Western markets, selling beryllium to Western producers and distributors from its substantial inventories. After an 8-year production stoppage, Ulba now offers a range of beryllium metal products including vacuum-cast ingots, powder, and hot-pressed powder (HPP) billets.

BWI concluded an agreement on September 4, 2003, to acquire about 25,000 lbs of vacuum-cast beryllium ingots annually from Ulba for ten years contingent on the material meeting certain minimum purity levels for use in production of AlBeMet.[13] Ulba claims that beryllium content is at least 99 percent for its ingots and 98.5 percent for the powder and HPP billets. However, according to BWI, so far Ulba beryllium cannot meet the purity specifications for key impurities such as iron, aluminum and silicon that BWI requires for high purity defense products.[14] The Ulba material is still being tested and it will be several years before BWI knows whether Ulba can even sustain the purity levels of current test samples of beryllium metal. However, Ulba is making concerted efforts to upgrade its capabilities and product quality and hopes its sales will reach $20-30 million in a few years.[15] Ulba also produces beryllium-copper material and components and BWI has a long-term agreement to buy beryllium-copper master alloy from Ulba.[16]

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[11] In September 2002, the Russian company and Ulba founded a 50/50 joint venture to promote sales of rolled beryllium-copper products in the Russian market, with Ulba producing billets and the Russian company using them to make rolled products. See www.ulba.kz. For 2002, the USGS reports beryl ore output of about 40 metric tons in Russia and only 4 metric ton in Kazakhstan, indicating that Ulba remains highly dependent on Russian ore concentrates. See U.S. Geological Survey, *Mineral Commodity Summaries 2003*, January 2003.

[12] In late 1999, in response to concerns of the Russian Ministry of Atomic Energy, Russia and Kazakhstan signed a draft agreement under which TVEL would be assigned interim "golden" shares in Ulba, giving TVEL the right to veto management decisions. Eventually, the golden shares would be converted into a 34 percent ownership share of Ulba. It is not clear that this agreement was consummated, but in October, 2001 TVEL, Kazatomprom, and the Ukrainian State Property Fund formed a joint-venture company to coordinate nuclear fuel activities. This might evolve into a more substantive operation by 2005. See "Kazakh Government Ratifies Nuclear Fuel JV Agreement," www.interfax.com.

[13] The agreement is actually with RWE NUKEM, Inc. of New York, a German-owned company that distributes Ulba's products in the U.S.

[14] BWI has not fully evaluated whether the Ulba material could reach required purity levels after multiple remeltings but this would not be cost-effective and preliminary tests indicate multiple remelting would be of limited effectiveness.

[15] Beginning in 1996, Ulba received some $4 million in funding from the International Science and Technology Center (ISTC) to upgrade its production and testing technologies. The ISTC is an intergovernmental organization established by agreement among the U.S., European Union, Japan, and the Russian Federation to provide opportunities for ex-Soviet weapons scientists to do peaceful science work.

[16] BWI negotiated a long-term agreement to purchase beryllium-copper master alloy from Ulba with deliveries to start in 2001. In July 2002 DOE announced a project to help Ulba expand and upgrade its production capacity for beryllium-copper master alloy, with DOE contributing some $1.5 million. Ulba

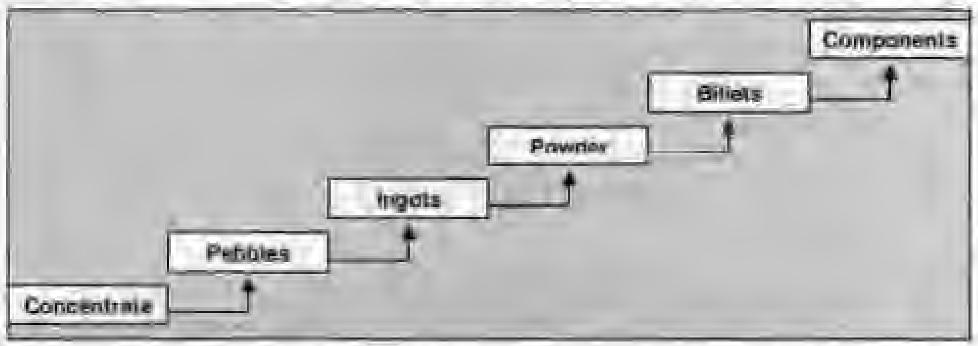
Chinese Producer

China is the third global producer of primary beryllium. The Ningxia Non-Ferrous Metal Research Institute is China's principal research and production site for beryllium. China has an autonomous production capability that includes mining beryl ore, producing beryllium metal, and fabricating components, especially for its strategic programs. Chinese beryllium metal and other beryllium-containing products are sold in Western markets to a limited extent. However, BWI has serious doubts whether the Chinese beryllium metal can meet the demanding purity levels and quantities required by most U.S. defense applications based on visits to the Chinese production facility. China's ongoing capacity to mine beryllium ore also is unclear.[17]

Beryllium Production Process and the Role of Scrap and Recycling

Factors affecting supply depletion are based on the production process for high purity beryllium at Brush Wellman's Ohio facility. Prior to being mothballed, the first stage plant employed chemical, thermal, and induction processes to remove impurities and convert the beryllium hydroxide into primary beryllium in the form of pebbles (thus the nickname "pebbles plant"). As displayed in Figure 1-2, the pebbles, in turn, served as

Figure 1-2: Stages in Production Process for Beryllium Metal



Source: Institute for Defense Analyses

feedstock for a multi-stage process that converts pebbles to vacuum-cast ingots, ingots to beryllium powder, powder to hot-pressed (HPP) billets, which in turn are machined into components. This multi-stage process is necessary because the coarse grain structure of the vacuum-cast ingot yields poor mechanical properties.

Alamos National Lab offering technical expertise, Ulba providing $4.5 million, and BWI investing $4 million. See "Kazakhstan: Ulba Metallurgy Plant," www.nti.org.

[17] Mine production was estimated to be 55 metric tons (of beryllium content) in 1999 and 15 metric tons in 2002. See U.S. Geological Survey, *Mineral Commodity Summaries 2000*, January 2000. More recently, there are reports that China has been importing beryllium-containing ores.

Machining is usually performed by commercial machine shops that contract with end users to produce beryllium parts.[18] However, BWI itself does a substantial amount of rough machining as well. For example, it converts generic billets into tailored starting shapes specified by outside machine shops and also uses extrusion and rolling processes to convert billet into bars, plates, sheets or foil.

Recyclable scrap is an important source of production material. A substantial amount of waste and scrap is generated in the production of beryllium metal and components. This leads to higher input requirements in the various production processes. At the same time, the ability to recycle substantial amounts of scrap represents an important source of production inputs. Therefore, this study distinguishes between scrap and waste, designating recyclable material as scrap and non-recyclable material as waste.

In the early stages of the production process at BWI's Ohio facility, vacuum cast ingots were created by combining beryllium pebbles from the now mothballed pebbles plant with "clean" beryllium scrap (i.e., meets broad impurity thresholds). The use of scrap reduces production costs by minimizing the amount of new beryllium employed.[19] While a 50:50 mix of primary beryllium and scrap is generally desired, the scrap share can be as high as 70-80 percent—but should be well short of 100 percent because of remaining impurities in the scrap. With the pebbles plant shutdown, a primary beryllium substitute for pebbles is needed to mix with scrap if BWI is to continue producing vacuum-cast ingot. For now, BWI continues to operate the process by substituting National Defense Stockpile ingots for pebbles as the source for primary beryllium.

Scrap generated during the beryllium metal production process ("home scrap") can be augmented by scrap generated by BWI's customers ("outside scrap") although recycling outside or new scrap requires a concerted effort by BWI and its customers. Outside scrap is significant because the overall average outside scrap rate is probably between 50 and 75 percent[20] and can exceed 95 percent for some critical parts produced by the Department of Energy (DOE).

That said, as beryllium feedstocks are increasingly depleted, the effective use of outside scrap becomes even more important. Typically, BWI sales contracts include provisions for buying back new scrap that customers will generate. The price offered is much lower than the sales price for new material and depends on the condition of the scrap returned. Customers must take care to minimize any contamination of the scrap by other materials. Often, they install special collectors to capture and transfer scrap from the moment it is generated. One report estimates that 80 percent of the outside new

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[18] Los Alamos National Laboratory has its own machining operation which can be employed to produce final parts on a small scale for certain nuclear weapons applications.

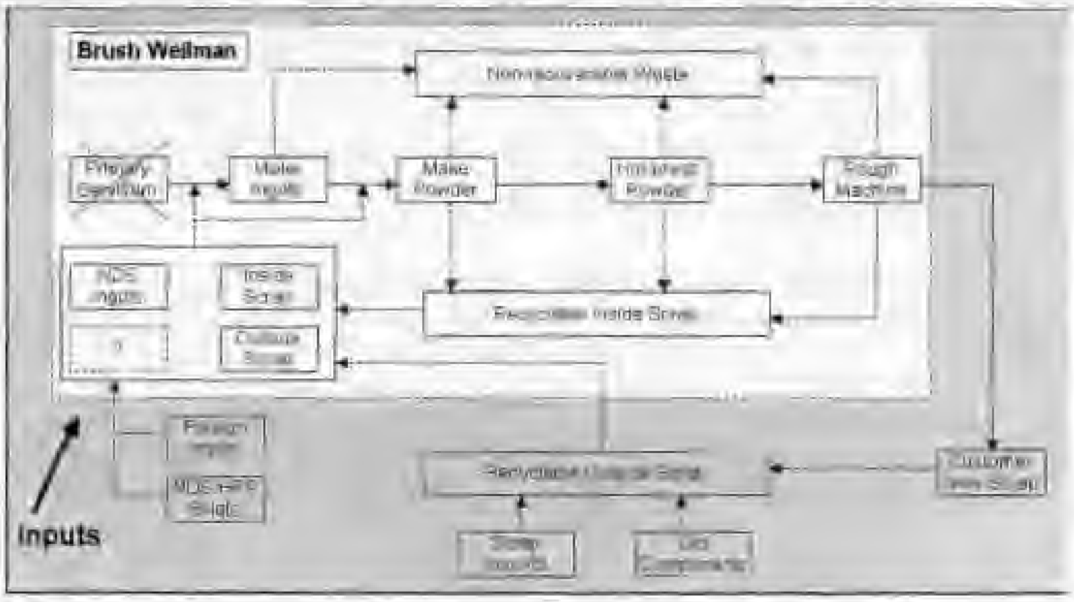
[19] To produce AlBeMet ingots, aluminum is included in the furnace charge. In this case, the purity requirements for the beryllium inputs are more relaxed than when high-purity beryllium ingots are made.

[20] The outside scrap rate is estimated at 50-60 percent in U.S. Department of Commerce, Bureau of Export Administration, *National Security Assessment of the U.S. Beryllium Sector*, July 1993, 62. A 75 percent rate is reported in National Materials Advisory Board, *Beryllium Metal Supply Options*, NMAB-452, 1989, 63.

scrap generated is returned for recycling.[21] Old scrap recovered from used components is also available sometimes. There have been instances where even DoD successfully collected and returned old scrap from weapon systems and components that were being phased out.[22] However, beryllium from components may be contaminated and efficient collection of old scrap can be a problem.

The overall process by which primary beryllium is converted to products using scrap is depicted on Figure 1-3. Home scrap amounts to 58 percent of the total input material—which is then recovered and used as input for the next production cycle.[23] While the generation and then recovery of inside scrap represents a substantial cost of production, this reprocessing of scrap yields reusable material equal to 80 percent of the scrap.

FIGURE 1-3: PRODUCTION CYCLE FOR BERYLLIUM METAL



Source: Institute for Defense Analyses

A number of production-related technologies that may also increase future beryllium supplies are being developed by BWI and others. These include improving the production of Near Net Shaping (NNS) forms, enhancing scrap recovery, and adapting the so-called Cambridge production process to beryllium. The Cambridge Process is a

[21] See U.S. Department of Commerce, Bureau of Export Administration, *National Security Assessment of the U.S. Beryllium Sector*, July 1993, 66.
[22] The Defense Reutilization and Marketing Service (DRMS) recycled substantial quantities of beryllium from the Poseidon program and when it was replaced by graphite in aircraft brakes.
[23] National Materials Advisory Board, *Beryllium Metal Supply Options*, NMAB-452, 1999.

new manufacturing technology that may be feasible for use in a new manufacturing facility to produce primary beryllium.[24]

Where feasible, the NNS approach can substantially reduce the amount of material that must be machined away, both inside and outside BWI.[25] The use of NNS production methods is promising. While the potential savings from NNS depend on the shape of the desired part, an overall average 30 percent reduction in the outside scrap rate seems reasonable over the next 15 years. Another area of manufacturing technology development is in recycling scrap. For example, BWI is implementing an AlBeMet chipper project to improve its ability to decontaminate AlBeMet scrap and possibly increase the amount recycled by 5000 lbs per year.

The Cambridge process as described previously is a new manufacturing process based on electrolytic de-oxidation (EDO). Instead of pebbles, such a process would produce sponge-like pellets of beryllium. The EDO process is a recent development by researchers in the United Kingdom who patented their approach globally in 1998. It is presently being developed for use in the production of titanium and could reduce the cost of that material by 40 percent.[27] In March, 2003, the Defense Advanced Research Projects Agency (DARPA) awarded funding for a four-year EDO development program for titanium manufacturing to a consortium led by Timet and including British Titanium, which holds the titanium sub-license for the process.

While the feasibility of EDO for producing beryllium metal has not been established, the process could provide a number of benefits, including lower costs, better quality, faster throughput, more modular factory design, and easier compliance with health and environmental regulations.[28] EDO operating costs for converting beryllium hydroxide to primary beryllium metal could be 50 percent or more below the costs of the current magnesium thermal reduction approach, lowering the cost of shipped products by 10-15 percent.[29] Moreover, preliminary estimates by BWI indicate that plant construction

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[26] The new process, based on electrolytic de-oxidation (EDO), has been described as follows when applied to titanium: "The titanium dioxide is made the cathode in a fused salt cell, and under an applied current the oxygen leaves the oxide as oxygen ions, diffuses to the anode, where it is discharged. The titanium metal is simply left behind and at no stage in the process is the titanium in the liquid or ionized state. This is the major difference with the previous processes." See www.britishtitanium.co.uk/technology.htm.

[25] Experiments by BWI on several parts indicated that NNS reduced the average scrap rate by 38 percent.

[27] This claim is cited in Professor Derek Fray, "Technological Breakthrough?" at www.msm.cam.ac.uk.

[28] Under the current process, BWI's mothballed pebble plant converted beryllium hydroxide to beryllium fluoride, which was then reduced with magnesium in the Kroll process. With EDO, the requirement to make beryllium fluoride, which accounts for about half of the cost of reducing beryllium, is eliminated. Instead, EDO reduces beryllium oxide, which is readily produced from beryllium hydroxide. Inputs to the reduction process include carbon anodes and electricity, which cost much less than the magnesium used in the Kroll process. The EDO process also operates at lower temperatures. Coupled with the elimination of the fluoride step, this should make containment of harmful emissions much easier.

[29] This assumes that pebble operations accounted for 20 to 30 percent of the cost of shipped products.

costs for a new primary beryllium facility could be 25-40 percent less using EDO rather than the current magnesium thermal reduction process.

At this point, there is no certainty that the EDO process will prove commercially feasible for beryllium or that such feasibility will be demonstrated before the depletion of NDS inventories. Some estimates project five to ten years before the question is resolved. However, because of preliminary work BWI has already funded with a private partner, the firm is optimistic that with Federal Government support the basic feasibility issues can be resolved in a year and that full development work can be completed in three years.[30] BWI is negotiating for access to know-how and intellectual property rights generated by others who are exploring the application of EDO to titanium. If EDO feasibility is not demonstrated in time to construct a new primary beryllium facility before NDS inventories approach depletion, any new production facility may have to be built using a modified version of existing production technology.

The existing magnesium thermal reduction approach remains viable for a new primary beryllium plant because of an increased understanding of how the beryllium manufacturing process affects health. As a result of recent cooperative research with the National Institute for Occupational Health and Safety (NIOSH) and medical surveillance internally funded by the firm, BWI is confident it can design and operate a new beryllium metal facility in compliance with OSHA regulations even using magnesium reduction technology. The part of BWI's plant that is still operating is meeting a beryllium workplace air standard that is an order of magnitude below that currently required. When the mothballed pebble facility was closed, BWI was facing litigation from both current and former employees and contractor employees related to the toxic hazards posed by beryllium. However, the court decisions and settlements related to that litigation so far suggest that health-related litigation is not likely to be a major financial obstacle to BWI's continued viability.[31]

NATIONAL DEFENSE STOCKPILE

Beryllium inventories at the NDS will help ensure that requirements for beryllium can be met until a new primary beryllium production facility is available. The vacuum cast ingot

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[30] A leading beryllium specialist at Los Alamos National Laboratory agrees with BWI on this assessment.

[31] BWI summarizes the current status as follows: "In the late 1990s nearly 200 people were suing the company with 12 trials pending. Approximately 45 percent of these plaintiffs were Government employees or employees of DOE's Management and Operating Contractors. These lawsuits claimed that the company had failed to provide adequate warnings about beryllium or had conspired with the federal government to hide the dangers of chronic beryllium disease, a potentially fatal lung ailment that afflicts a small minority of people whose immune systems are susceptible. In the past two years, Brush has received favorable verdicts in two jury trials, and favorable summary judgments (where the magistrate determines that the weight of evidence does not support the allegations by the plaintiff) in five more venues. As a result, most of the remaining cases have been settled for nominal costs (nuisance value). While a few cases remain, the number is comparable to the product liability case load prior to the large number filed in the late 1990s."

portion of the stockpile, is, to a large extent, already contractually committed to BWI.[32] The remainder of the beryllium metal stockpile is in the form of hot pressed powder (HPP) billets.[33] The billet inventories must be carefully managed, both to serve as a reserve for potential future DOE and DoD emergencies and, if necessary, to support interim consumption requirements once a new production facility is close to coming on-line.[34]

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[32] BWI actually takes delivery and pays for the ingots only as they are needed. As of March 15, 2004, there were approximately 203,000 pounds of ingots left for purchase under the contract plus 10,000 pounds of ingot not yet offered for sale.

[33] The NDS holds 342,000 lbs of HPP billets. The NDS goal for the beryllium metal inventory was set in 1999 by Congress at 100,000 pounds (50 short tons). This goal was designed primarily to meet potential DOE contingencies. However, in its 2003 Report to Congress on NDS Requirements, DoD informed Congress that the goal should be increased to include all of the 342,000 lbs of HPP billets, pending further clarification of the future supply situation for both DoD and DOE requirements. The HPP billet inventory is not necessarily usable by BWI as HPP product *per se*. A small portion of the inventory would not satisfy current HPP purity standards, having been manufactured to non-standard or obsolete specifications. About 13 percent of the HPP billets are Grade C and have only 94 percent pure beryllium and include relatively high amounts of beryllium oxide, iron, carbon, and aluminum. However, the remainder of the billet material would be usable for beryllium metal applications either directly or if re-melted, i.e., used as input for vacuum-cast ingots. Of course, re-melting results in some loss of material, as discussed above. It is not clear how much of the inventory could be used without re-melting, but some portion might be suitable as input directly for making powder or for rough machining.

[34] If authorized for release to industry, the billet reserves would have to be made available through sales contracts in compliance with Section 2(c) of the Stock Piling Act.

Chapter Two: Beryllium Applications and Demand

This purpose of this chapter is to provide estimates of domestic and foreign demand through 2020 for beryllium metal from the current domestic producer, Brush Wellman Inc. (BWI). Foreign customers are important because most of them are defense-related. After describing beryllium's unique properties, the chapter reviews historical and current consumption and projects an average growth rate of six percent a year through 2009 from the current demand of 35,000 pounds.[35] The estimated growth rate is based on bottom-up assessments of demand for defense and essential civilian customers (including foreign customers). The text also notes that while the likely growth rate will be lower or negative for the years 2010 to 2020, the six percent growth rate is employed in the analysis as an adverse case scenario.[36]

Demand Linked to Beryllium's Physical Properties

Beryllium is a special material with a unique combination of properties. While materials such as aluminum and copper are available for less than $1 per pound, and titanium can be purchased for $10-100 per pound, the average price for pure beryllium metal is about $400 per pound and special grades can cost much more. Beryllium is nevertheless selected for use in a number of key defense and other applications that uniquely benefit from its properties.

Most importantly, beryllium is a light metal, one-third lighter than aluminum. This makes beryllium a candidate for aerospace and other applications where low weight is essential. However, it is beryllium's other properties that make it stand out within the group of light metals. It is an extremely stiff material, in both absolute terms and relative to its weight. Its stiffness-to-weight ratio (i.e., specific stiffness) is six times greater than steel, aluminum, or titanium. Its strength-to weight ratio (i.e., specific strength) is comparable to steel and other materials at moderate temperatures and, with a high melting point, it retains useful strength at temperatures far above the melting points of aluminum and magnesium. The combination of stiffness and strength makes beryllium a prime candidate for applications where structural integrity is essential.

Further, beryllium has a moderate coefficient of thermal expansion, making it compatible for use with steel and other materials that expand and contract moderately. Another valuable characteristic of beryllium is that it absorbs and dissipates heat quickly, making it useful as a heat sink or shield. In addition, beryllium is very highly reflective to infrared wavelengths, giving it utility as a mirror in infrared applications.[37]

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[35] In this Study, quantities of beryllium consumed are based on the beryllium metal content of shipments rather than the gross weight of beryllium containing material delivered which would vary between beryllium metal and AlBeMet.

[36] Chapter Three demonstrates the impact of considering alternative growth rates both in the short and long run.

[37] Beryllium polished as a mirror is highly reflective to infrared radiation. Beryllium is also used as a substrate coated with another material that constitutes the mirror surface, for example, to reflect visible light.

For many applications, graphite composites represent the principal competitor for beryllium. Composites can be even lighter than beryllium, with relatively high specific stiffness and excellent heat absorption and dissipation qualities. However, beryllium can be formed into shapes that are much more complex than those achievable with composites.[38]

There are also certain disadvantages to using beryllium in addition to its high price. It is a brittle material, which can make it difficult and costly to machine into usable components. Achieving adequate properties by casting the metal has not always proven feasible, so complex shapes often must be formed by machining large blocks of the metal and generating considerable scrap in the process. The development of aluminum-beryllium composites, such as BWI's AlBeMet, has helped overcome some of these problems. However, as noted earlier, beryllium is also toxic when being produced and machined and concerns about the health and environmental risks associated with breathing it will have some impact on demand in applications where substitutes are available.[39] Complying with related OSHA and EPA regulations adds to the complexity and cost of manufacturing with beryllium.

In addition to the physical and mechanical properties discussed above, beryllium is well known for its remarkable combination of nuclear properties that make it useful in nuclear reactors and warheads.[40]

LONG TERM CONSUMPTION TRENDS

HISTORICAL PATTERNS

The pattern of beryllium consumption in the U.S. has been volatile and evolving over the past half century. Figure 2-1 traces all forms of beryllium consumption, including pure beryllium metal and the beryllium contained in AlBeMet; oxide powder; and beryllium-copper.[41] Following its early use in nuclear applications, beryllium metal became a commercially available material in the 1950s. Missile and space programs found uses

[38] See Defense Contract Management Agency, Industrial Analysis Center, "Beryllium Industrial Base Assessment," September 2002, 3

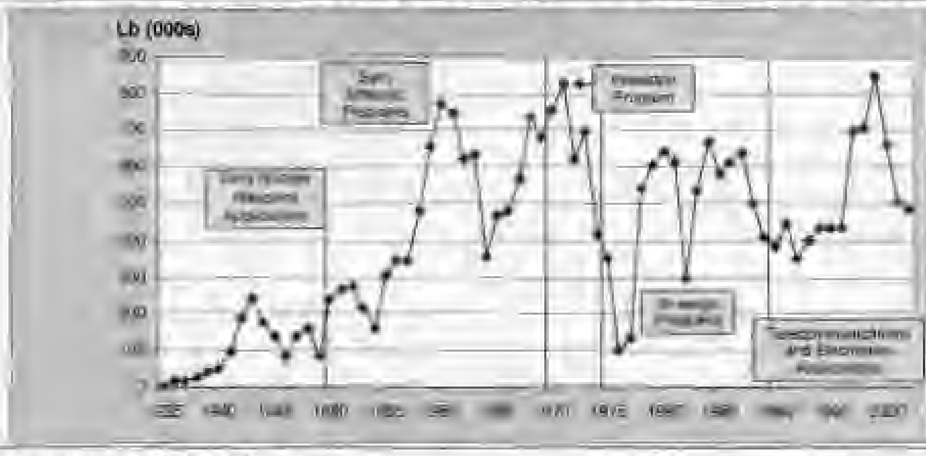
[39] DOE training materials note that inhalation of airborne beryllium particles may lead to beryllium sensitivity, chronic or acute beryllium disease, or lung cancer. See http://tis.eh.doe.gov/training/be/Be08.html. Finished beryllium parts do not pose a health risk except where abrasion or corrosion might release beryllium into the environment. See Defense Contract Management Agency, Industrial Analysis Center, "Beryllium Industrial Base Assessment," September 2002, 3

[40] Beryllium has a very low cross section for absorption of thermal neutrons, making it an excellent choice as a neutron reflector to block neutron leakage in reactors and warheads. At the same time, it has a high scattering cross section that works to slow neutron speed, a trait that is useful for moderating reactor performance. In conjunction with beryllium's low weight, these characteristics make it particularly desirable for small, mobile reactors and warheads. Finally, in conjunction with an alpha-emitting material such as polonium or radium, beryllium can be a source of neutrons and even an initiator for nuclear reactions.

[41] The table is based on data reported U.S. Geological Survey, "Historical Statistics for Mineral Commodities in the United States," OF-01-006.

for beryllium in subsequent years, with the periodic demise of such programs accounting for the saw tooth consumption pattern. For example, the 5-year Poseidon program consumed some 400,000 lbs in a five-year period around 1970 and then stopped.

FIGURE 2-1: APPARENT U.S. CONSUMPTION OF BERYLLIUM (ALL FORMS)



Source: Institute for Defense Analyses

Strategic programs again helped boost consumption during the 1980s. Yet end users continued to search for new materials that could surpass beryllium's advantages or avoid its disadvantages. In particular, carbon composites replaced beryllium in a number of applications when they proved to be lightweight, stiff, heat-absorbing, and often less costly. For example, carbon materials replaced beryllium in brakes for the Space Shuttle and military aircraft, in heat shields for space capsules and reentry vehicles, and in commercial nuclear power reactors, for technical or economic reasons.[42] But other aerospace applications developed since beryllium's low weight, stiffness and strength provide structural support and dimensional stability (e.g., in housing sensitive instruments and optics). Moreover, the huge consumption surge in the late 1990s reflects increased use of beryllium-copper alloy in telecommunications and electronic applications.

Note that over the decades the consumption of high purity beryllium metal relative to lower purity metal has dropped dramatically, with beryllium-copper now accounting for the majority of consumption reflected in Figure 2-1.[43]

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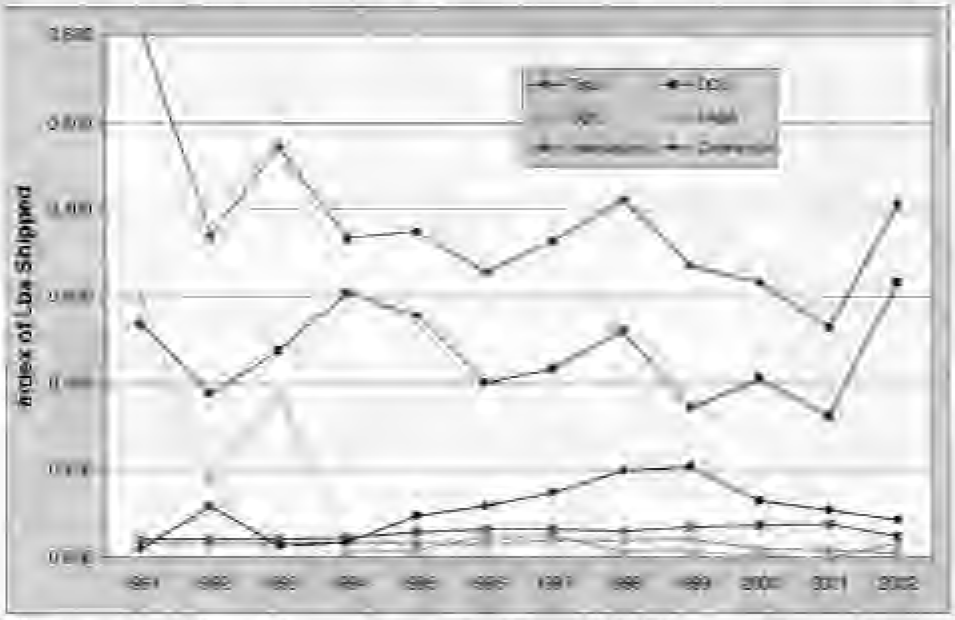
[42] NASA, for example, concluded that carbon for the Space Shuttle brakes would be cheaper, lighter, longer-lasting, and could withstand braking temperatures 2-3 times higher than beryllium could. For the C-5B, carbon heat sinks for brakes were some 400 lbs lighter than the beryllium heat sinks used on the C-5A. For nuclear power reactors, the lower cost of graphite reflectors seemed to outweigh the technical advantages of beryllium reflectors. See Roskill Information Services, *The Economics of Beryllium*, Fifth Edition, November 1989, 39-53.

[43] See U.S. Geological Survey, "Minerals Yearbook, Beryllium," 2002. For example, consumption during 1999 exceeded the previous consumption peaks of 1960 and 1971 but consumption in the form of pure beryllium metal was much lower in 1999 than in 1960 and 1971.

Figure 2-2 focuses on consumption of beryllium metal (including AlBeMet) over the most recent decade.[44] Total consumption moved downward over the period, declining at an average year-to-year rate of almost four percent. As shown in the figure,

FIGURE 2-2: CONSUMPTION OF BERYLLIUM METAL (INCLUDING ALBEMET)



Source: Institute for Defense Analyses

much of the decline reflects the precipitous drop in sales to DOE as strategic programs wound down in the early 1990s. DoD-related consumption was more stable, declining by an average year-to-year rate of only 1 percent and jumping sharply at the end of the period due to higher spending for defense procurement and new programs using beryllium. The trend for commercial uses was solidly upward for most of the period but fell off after 1999. Overall, commercial use in the 1990s rose at an average annual rate of 13 percent—albeit from a much lower base than DoE or DoD applications in the early 1990s.

The decline in DoD consumption of beryllium metal during the 1990s occurred during a period of relatively weak defense spending. From 1991 to 1997, DoD procurement of systems dropped by 31 percent and DoD consumption of beryllium metal declined by about 19 percent. Much of the recent growth in DoD procurement has been for electronics, which includes subsystems that utilize beryllium metal.

[44] The consumption index represents the relative quantities of beryllium consumed over time by different customer groups. It is constructed based on sales data, adjusted for price changes and for certain factors that do not reflect material consumption. For example, the index excludes material produced for the NDS.

Current Defense Application Trends

Discussions with DoD program offices and BWI indicate that beryllium applications in the short and medium run fall into two categories in terms of substitutability as outlined in Table 2-2. The first group on the table represents applications for which currently there are no suitable substitutes: although R&D programs are searching for substitutes in a few cases, beryllium metal is essential to achieving system performance requirements. The second group includes applications for which beryllium offers the

Table 2-2: Availability of Substitutes for Beryllium in Selected Applications

Critical strategic applications with no suitable substitute for beryllium:
Maintenance of the strategic nuclear weapons stockpile
Surveillance satellites
Ballistic missile defense systems
Guidance systems on existing strategic missiles
Airborne FLIR systems for fighters and attack helicopters
Reflectors for high flux, nuclear test reactors
Market uses where beryllium or high-beryllium alloys offer the best technical solution:
Communications and weather forecasting satellites
Guidance/control and electro-optical systems
Electronic countermeasures and avionics for helicopters and fighter aircraft
Commercial robotics, computers, and other high-technology systems critical to the civilian infrastructure and often support military needs
Low energy, high resolution x-ray imaging for soft tissue (e.g. mammography)
Detectors for particle physics research
Fusion energy

Source: Institute for Defense Analyses

best technical solution; substitution of other materials is possible, perhaps with some degradation of performance. Roughly half of recent U.S. beryllium shipments were for defense-related applications in the first group.

The amount of beryllium metal that will be needed for defense-related purposes in the future depends on the continuing defense procurement cycle and the evolution of materials technology. Beryllium will find new users but lose old users. A list of specific defense systems that are key to future beryllium demand in the short and long term appears in Table 2-3. The table distinguishes between three types of applications:

TABLE 2-3: RECENT AND FUTURE DEFENSE APPLICATIONS FOR BERYLLIUM METAL

1. Programs from the late 1980s/early 1990s for which sales are now declining
Mast-mounted sight
LANTIRN targeting pod
Minuteman guidance maintenance
M1A2 upgrade to optical sight
Missile seeker systems
2. Programs developing from the early to mid 1990s and into the next 5-10 year period
F-22 avionics
Modern FLIR systems, e.g., ATP, ATFLIR, IFTS, Arrowhead, EOSS, EOTS
Missile defense applications, e.g., EKV, SBIRS, Leap, and PAC 3
Military and commercial satellite electronic housings
Satellite structural components, including ion engine
THAAD
NSM sensor housing
3. Programs that are in development now for applications over the next 15 years
Joint Strike Fighter (avionics, lift fan)
Smaller missile systems, seekers (CMM)
LOROP applications (9120, SPIRITT)
Radar systems
Global Hawk ISS
Future Combat System (FCS)
Guidance (Trident upgrade, retro-fit, others?)
Other Classified Systems

Source: Institute for Defense Analyses

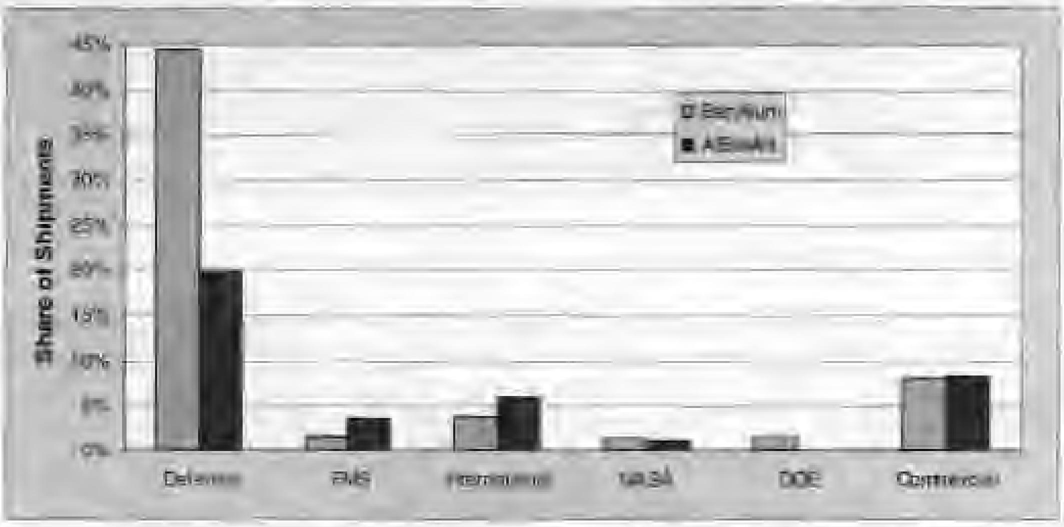
those winding down, current applications in advanced development or recently deployed, and future long term applications for which beryllium metal is a candidate material or beryllium components are already being fabricated and tested. These latter programs represent potential applications that will drive consumption at the end of the decade and into the future. For example, the Joint Strike Fighter is potentially a substantial user of beryllium. To be sure, decisions to include or exclude beryllium in key systems could significantly impact the consumption totals. The level of beryllium consumption will likely remain volatile in the long run. A detailed description of defense applications that are likely to impact long term beryllium demand appears at Appendix A.

DEFENSE AND OTHER CONSUMPTION OF BERYLLIUM METAL

As noted above, DoD is the dominant end user for high purity beryllium metal. However, some non-DoD organizations consume beryllium for defense-related purposes or civilian applications of national importance. This section briefly characterizes the various types of users and compares defense and non-defense users.

Recent beryllium consumption for selected users is summarized in Figure 2-3. DoD consumption accounted for 64 percent of the beryllium metal that was shipped during 2000-2002.[45] Foreign government users (also linked in most cases to defense) consumed about 15 percent while commercial organizations used about 16 percent of the total. Note that the figure distinguishes between foreign military sales (FMS), which are sales of U.S.-made military systems that contain beryllium to foreign governments, and international sales, which are sales of U.S.-made beryllium materials for use by foreign governments.[46] NASA and DOE are important beryllium users but their recent consumption levels have been relatively low.

FIGURE 2-3: AVERAGE SHIPMENT SHARES BY USER (2000-2002)



Source: Institute for Defense Analyses

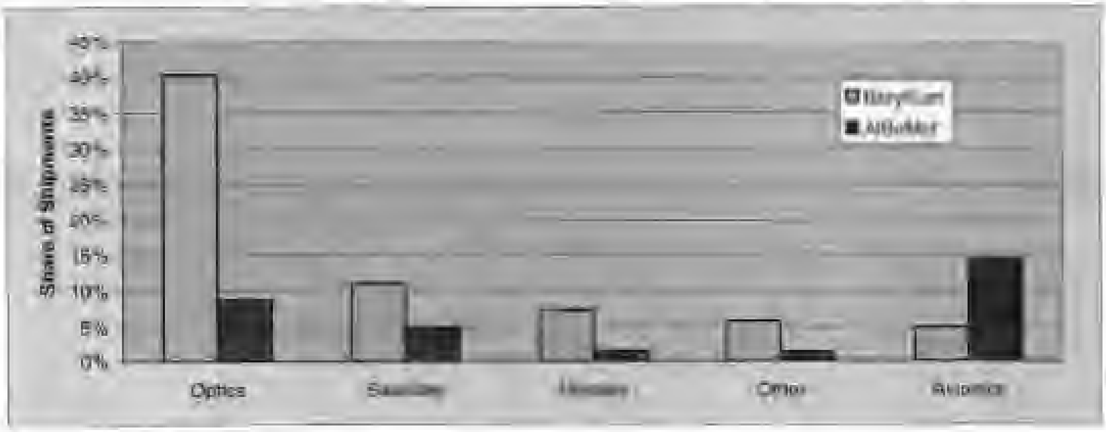
Figure 2-3 also offers insight into the growing use of beryllium metal in the form of AlBeMet, which accounted for some 39 percent of beryllium content shipped. Pure beryllium metal dominated consumption by DoD but AlBeMet use was also significant. The same pattern holds for non-DoD and commercial applications; only DoE made no use of AlBeMet due to its very specialized requirements.

[45] Measured in terms of beryllium content of the material shipped.

[46] Sales are considered commercial if the foreign end user is a commercial organization.

The principal types of DoD applications by broad category are indicated on Figure 2-4. Nearly half of DOD's beryllium usage is for optical applications, particularly the forward-looking infrared (FLIR) sensor systems. Optical uses also include the structure for the mast-mounted sight on the OH-58D Kiowa Warrior scout helicopter and the commander's sight on the M1 tank. Other key applications include missiles

FIGURE 2-4: DOD APPLICATIONS FOR BERYLLIUM METAL (2000-2002)



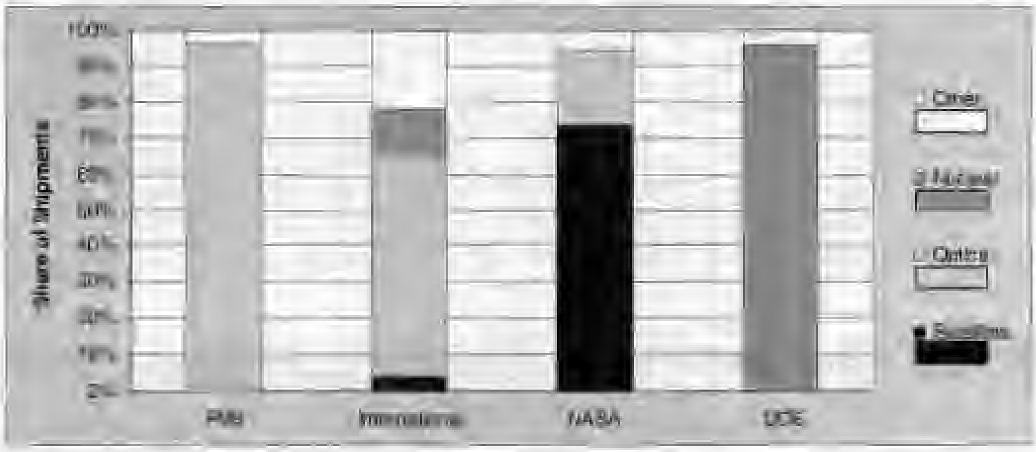
Source: Institute for Defense Analyses

and satellites. Upgrades of existing offensive missiles and applications for ballistic missile defense were major missile and satellite consumers. However, as noted earlier, the Missile Defense Agency is actively seeking substitutes for beryllium. Avionics applications have also consumed a significant amount of beryllium metal recently, particularly the F/A-22 Raptor.

Figure 2-5 shows international and non-U.S. beryllium applications. For FMS users, virtually all of the beryllium metal consumed in 2000-2002 was for optics. This especially includes beryllium in FLIR systems on U.S.-made military aircraft.[47]

[47] For example, the United Arab Emirates ordered 80 F-16 fighters, to be delivered between 2004 and 2007. The fighters include an integrated FLIR targeting system (IFTS) that uses beryllium. See www.f16falcon.com/facts/f16_4d.html.

FIGURE 2-5: INTERNATIONAL AND NON-U.S. APPLICATIONS OF BERYLLIUM METAL (2000-2002)



Source: Institute for Defense Analyses

For international users, beryllium consumption is primarily for optics but also for satellites and nuclear uses. Included in nuclear applications are beryllium reflectors for nuclear power plants, test reactors, and weapons. For example, in recent years the UK purchased a few hundred pounds of beryllium metal for weapons applications. In addition, beryllium is a prime candidate for use as a shielding material on the International Thermonuclear Experimental Reactor (ITER) project, which will explore energy production through nuclear fusion.[48] Other foreign purchasers of beryllium metal include Israel for the Arrow missile, France for the Damocles targeting pod, several European countries for tank optics (e.g., on the Leopard Tank), and for the OSIRIS mast-mounted sight used on the NH-90 helicopter.[49]

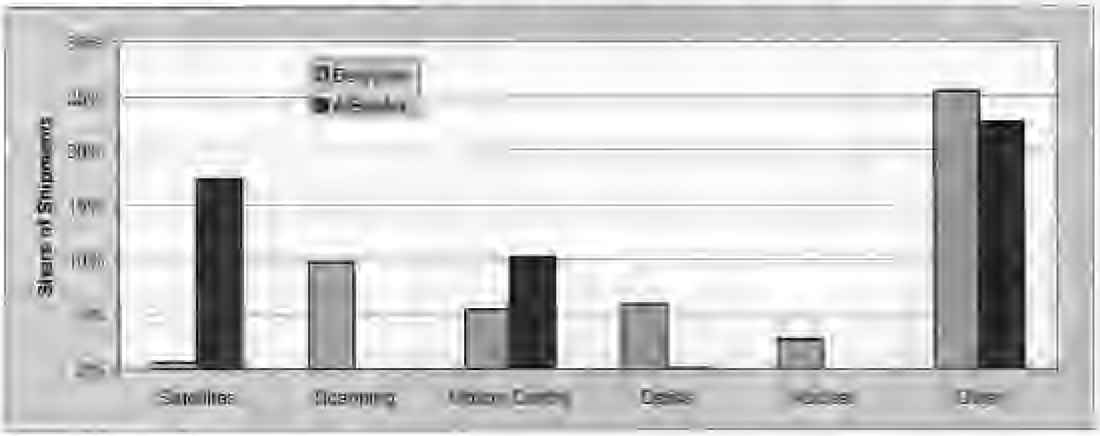
NASA uses beryllium metal primarily for satellites and other spacecraft, and also for astronomical telescopes. Current beryllium metal consumption at DOE is primarily for reflectors at test reactors. These nuclear reactors are used for research on nuclear energy as well as applications of direct interest to DoD. For example, the Advanced Test Reactor (ATR) at the Idaho National Engineering and Environmental Laboratory (INEEL) is used primarily for the Naval Nuclear Propulsion Program. The test reactors represent modest but continuing beryllium requirements since their reflectors must be replaced every six or seven years. Nuclear weapons production is now minimal, but DOE has certain contingency weapons requirements that could generate a substantial need for beryllium metal, as discussed below.

[48] Beryllium's nuclear properties, high melting point, and resistance to cracking make it useful in the shielding blanket as the armor material facing the plasma, helping to contain and stabilize it. ITER is an international project that began in 1988 and now includes the European Union, Japan, Russia, Canada, and the U.S. Negotiations on a ten-year construction project for an ITER facility are now underway, with DOE representing the U.S. See www.iter.org and www.ofes.fusion.doe.gov.

[49] Any beryllium sales to foreign co-producers of U.S.-designed systems such as the F-16 or the Joint Strike Fighter would also be considered international sales.

Commercial users have a fairly wide assortment of applications for beryllium metal. As shown on Figure 2-6, the largest single use for AlBeMet is for satellites. Other significant uses include scanning and motion controls, which together account for about 26 percent of commercial consumption. These are mainly industrial applications, for example, for manufacturing and automated inspection. Beryllium is used in mirrors for laser scanners and in structural and robotic components and for motion control. Scanner applications include semiconductor imaging and mask inspection, printing, engraving, welding, medical equipment, and scientific instruments. One noteworthy use is for x-ray generators and detectors, which take advantage of beryllium's transparency to x-rays. Ultra-thin beryllium foil is used for the x-ray window in medical devices employed, for example, for mammograms.

FIGURE 2-6: COMMERCIAL APPLICATIONS OF BERYLLIUM METAL (2000-2002)



Source: Institute for Defense Analyses

Nuclear power plants also account for a modest share of commercial beryllium consumption. The "Other" category on Figure 2-6 includes a wide variety of applications including, for example, some use of beryllium in automobiles.

THE NECESSITY TO PLAN FOR DOE CONTINGENCIES

The National Nuclear Security Administration (NNSA) at DOE is responsible for the nuclear weapons stockpile and has a special role in the monitoring and refurbishment of existing nuclear weapons and the manufacture of new weapons if necessary. Its role in these stockpile requirements is defined by the Nuclear Weapons Council in the Nuclear Weapons Stockpile Memorandum. Pure beryllium metal plays an important role in the primary stage of many nuclear weapons. In the future, the NNSA may require beryllium for ongoing work and in the event of certain contingencies.

NNSA currently plans to refurbish and modernize weapons in the nuclear stockpile, beginning in FY2006 for selected weapons. Refurbishment includes the replacement of limited-life components, but it is not clear that this will generate substantial requirements for beryllium.[50] NNSA is also responsible for ongoing surveillance of weapons in the stockpile to assure that NNSA can certify their performance readiness. This process includes dismantling a sample of weapons so that their condition can be examined. NNSA has a requirement to manufacture pits to replace those that are dismantled, beginning in FY 2007.[51] However, this is unlikely to generate large beryllium requirements, especially since NNSA has only a limited capability to manufacture pits.[52]

Certain nuclear weapons contingencies could, however, generate large immediate requirements for beryllium.[53] For example, the nuclear weapons surveillance process potentially could uncover unexpected aging or other problems with the stockpile weapons. In the extreme case, NNSA might find itself unable to certify the performance of the weapons, forcing an emergency requirement for refurbishing large numbers of existing weapons or manufacturing new ones. NNSA's requirements for production readiness include a surge capacity to replace components in any one type of weapon at the rate of 10 percent of the START I limit per year, with the first weapon to be completed within three years after the need is defined.[54] Other potential contingencies could include a need to manufacture new special-purpose weapons or reconstitute forces at a higher level in response to new national requirements. While an emergency could generate large total requirements for beryllium, NNSA would be able to consume only a part of that large beryllium requirement each year because of production capacity constraints.[55]

In a contingency, the DOE requirement for beryllium also will be impacted to a lesser extent by the degree to which scrap from DOE machining of beryllium metal during parts production for nuclear weapons could be recycled to purity levels sufficient for use in production of new beryllium metal by BWI. This is potentially significant because DOE scrap rates per part can reach over 95 percent of the initial beryllium metal provided by BWI. Los Alamos National Laboratory (LANL) and BWI disagree about the potential for recycling scrap from parts production to meet any future weapons contingency. Based on its prior experience in recycling Rocky Flats scrap, BWI is confident that it can recycle significant amounts of scrap from any DOE pit production

[50] NNSA notes that almost every component, including pit components, could require replacement over an extended lifetime. See NNSA, "Infrastructure Plan for the NNSA Nuclear Complex," April, 2003, 10-11.
[51] See NNSA, "Infrastructure Plan for the NNSA Nuclear Complex," April 2003, 12.
[52] DoE's major pit production facility at Rocky Flats, Colorado was shut down in 1989 with the end of the Cold War. NNSA has established a limited interim capability to manufacture pits and related components at Los Alamos National Laboratory (LANL).[56] For production of large numbers of pits, a new production facility must be built, named by DOE the Modern Pit Facility (MPF). That facility would be constructed by 2020 if budget approval is granted and a decision on whether to proceed is expected during 2004. If the MPF does not receive budget approval, the interim facility at LANL would be gradually expanded but not to the capacity level of the MPF.
[53] For example, these estimates appear in LANL report "Beryllium Metal Requirements for Future Nuclear Weapons (U)", LA-CP-01-136, April 10, 2001 by Nelson S. DeMuth and Stephen P. Abeln.
[54] See NNSA, "Infrastructure Plan for the NNSA Nuclear Complex," April 2003, 14.
[55] For example, if the proposed MPF facility were built, NNSA would be limited by its annual pit production capacity. If an emergency occurred in the absence of the MPF, it would take time measured in years to install a sufficient pit production capability.

facility. DOE disagrees, citing the differences between the scrap beryllium provided from Rocky Flats and what would be provided from a new pit production facility.

Regardless of which recycling assessment is correct, the major point is that DOE does not have sufficient production facilities for certain key components in the primary stage to meet within two years any large emergency requirement to replace a large percentage of U.S. nuclear weapons. Therefore, if a new domestic beryllium production facility were scheduled to come on-line within a few years of the depletion of other NDS inventories of beryllium, release of the NDS billet reserves could meet both normal demand and contingent DOE requirements on an annual basis.

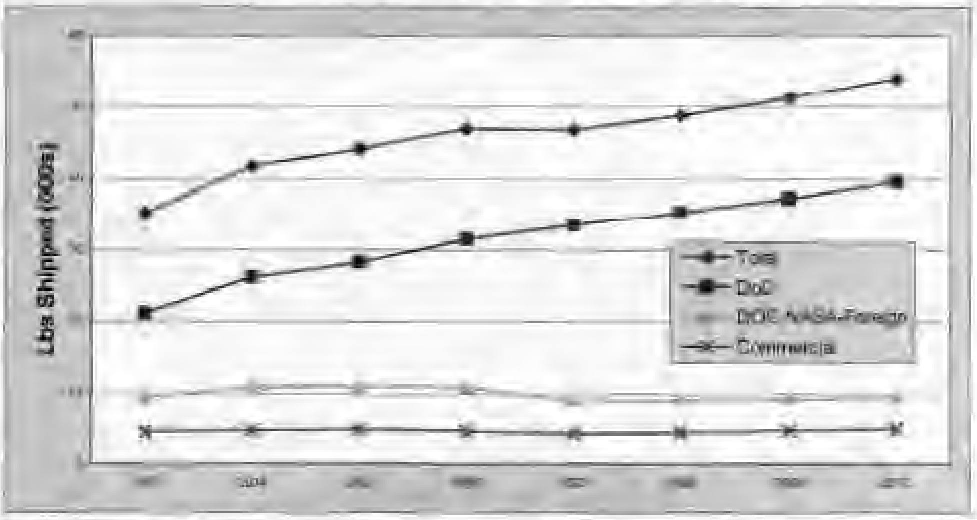
Current Demand and Future Requirements: The Baseline Case Scenario

During 2000-2003, total consumption of beryllium metal increased at an average annual rate of about 6 percent reaching a total of roughly 35,000 pounds in 2003. For the most part, this four-year growth was driven by a 20 percent average annual increase in defense-related consumption. Consumption for other purposes generally declined. For the next five years, a 6 percent growth assumption is viewed as a plausible assessment supported by bottom-up demand and confirmed by BWI's own forecasts.[57] The potential for higher consumption in non-defense optical applications seems solid for the coming decade. Growth in requirements seems likely to continue with total demand estimated at close to 50,000 pounds by 2008—however, the prospects for continued growth beyond 2009-2010 are less clear. For example, the cancellation of one or two major aircraft programs would eliminate growth for defense purposes entirely but leave a substantial requirement for the metal at or near 40,000 pounds per year for defense purposes.

Figure 2-7 forecasts shipments through 2010 of beryllium metal content, based on discussions with DoD program offices, beryllium suppliers and other market participants. The forecast is most reliable during the first few years, when growth is projected to average somewhat more than six percent. Defense programs account for virtually all growth. Shipments to DOE, NASA, and foreign governments, which may be defense-related, are expected to decrease somewhat. Shipments to commercial users are forecast to increase, but only slightly.

[57] Many DoD program offices are not aware of how much beryllium is purchased and used for their systems. As a result, consultation with BWI provided a useful independent bottom-up forecast based on their extensive discussions with their customers.

FIGURE 2-7: FORECAST OF BERYLLIUM (2004-2010)



Source: Institute for Defense Analyses

Uninterrupted growth in demand beyond 2010, although less certain, is also a possibility that this study must take into account as part of an adverse case perspective. Even in the medium run (2007-2011) when NDS ingots could be exhausted (depending on the availability of imports), it is important that DoD policy be based on a sufficient demand assumption for defense-related programs that it not face a beryllium shortage. However, for the second period under study (2010-2020), the six percent annual growth is a very generous assumption, considering that requirements for metals tend to be cyclical and beryllium demand declined at an average rate of 3.6 percent during the last down cycle from 1991 to 2002. A number of factors could easily lead to similar or even greater percentage declines in consumption.

Since a continued six percent average annual growth through 2020 for beryllium metal would be unprecedented, the alternative cases in the next chapter explore not only alternative growth rates for the entire period but the more likely possibility that a period of immediate high growth rate will be followed by a declining or negative growth rate for beryllium metal.

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Chapter Three: Supply Depletion Estimates

This chapter describes projected supply depletion dates for beryllium metal employing a supply depletion model. The model projects how soon a supply deficit will occur for various supply/demand scenarios based on alternative supply assumptions about the availability of imports and NDS inventories as well as various assumptions about demand over time.[58] The four scenario factors that vary are outlined in the table below:

Figure 3-1: Supply Depletion Model Scenarios

Scenario	Assumptions
Base Case	{ No imports available, No release of NDS billets, Constant 6 percent growth rate } One scenario
Additional supply	• Imports only; • Imports and NDS billets; • NDS billets only
Different growth rates	• Minus 4 percent ; • Plus 1 percent; • Plus 11 pecent; • Plus 16 percent
Timing of growth rates change	• Constant rate for entire period • Shifts from 6 percent to higher or lower rate at 2010

Source: Institute for Defense Analyses

Base Case Results

Table 3-1 illustrates how the model determines the supply depletion date using a Base Case. Because the Base Case assumes no imports are available and no NDS billets have been released for sale, it is used as a basis for comparison with those scenarios that reflect more likely supply assumptions but which also embody policies concerning those assumptions. Each year, the model uses all of the available outside scrap and meets the balance of the input requirement with ingots. For the 2004-2007 period, the total input requirement for the Base Case is satisfied and BWI produces sufficient material to meet its projected orders for shipments. However, in 2008, the ingot supply is finally depleted and a supply deficit occurs. Outside scrap and the last of the ingot are sufficient to meet a little more than half of the 2008 requirements. In subsequent years, there is hardly any production at all as the outside scrap supply quickly disappears.[59]

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[58] The model's starting point is an assumed set of annual requirements for shipments of beryllium metal products to all of BWI's domestic and foreign customers broken down proportionately between pure beryllium metal and AlBeMet for each year as well as the percentage of each that can be considered near net shaped and thus the amount of recyclable scrap available as well.

[59] The availability of recycled outside scrap depends on the level of shipments during the prior year.

TABLE 3-1: INPUT SUPPLY PROFILE FOR BASE CASE (000 LBS)

Year	Available Supply of Outside Inputs: Outside Scrap	Foreign Supply	NDS VC Ingots	NDS HPP Billets	Total	Reqm't	Deficit	Share Reqm't
2003	10	0	42	0	52	52	0	1.00
2004	10	0	45	0	56	56	0	1.00
2005	11	0	48	0	59	59	0	1.00
2006	12	0	51	0	62	62	0	1.00
2007	12	0	54	0	66	66	0	1.00
2008	13	0	30	0	43	70	-27	0.61
2009	8	0	0	0	8	74	-66	0.11
2010	2	0	0	0	2	79	-77	0.02

Source: Institute for Defense Analyses

ALTERNATIVE CASE RESULTS

The depletion date of beryllium metal supplies can be postponed or accelerated depending on availability of new sources of production or different growth rates in demand. This section assesses the impact of different demand and supply assumptions. On the supply side, it indicates the effect of importing vacuum-cast ingots from Kazakhstan (even if limited to low purity applications) and/or releasing hot pressed powder (HPP) billets from remaining NDS inventories. On the demand side, it reviews the effect of two lower growth rates and two higher growth rates for the entire 17-year period and growth rates that change after 2009. The analysis focuses on how the alternatives would affect the depletion date. Alternative policies for avoiding a depletion of beryllium feedstock are reviewed in the next chapter.

ADDED SUPPLY SOURCES: IMPORTS AND NDS BILLETS

The middle column of Table 3-2 uses the six percent demand growth scenario of the Base Case and applies seven alternative scenarios in which imports and/or sales of NDS billets at various levels extend the beryllium supply depletion date. The resulting depletion dates are highlighted in the middle of the table. The results indicate that if imports of 25,000 pounds annually prove reliable for low purity applications, the depletion date would be extended three years until 2011 (Case One) with no release of NDS billet reserves. If the same import assumption were supplemented by release of 70 percent of the billet reserves once NDS ingots are depleted, the depletion date would be extended another four years until 2015 (Case Two).

Even if imports prove unreliable for quality or other reasons, results for Cases Four and Five in the middle column indicate that release of part or all of the NDS billet reserves would extend the depletion date to 2012 and 2013, respectively. Cases Six and Seven consider scenarios involving imports of 50,000 pounds per year. The results from all these cases employing a six percent growth rate suggest that there should be sufficient time to select and implement a long-term solution to the beryllium supply problem and still allow for a few years of R&D on a new primary beryllium production process as well as design, permitting, construction, equipping and testing of a new plant.

TABLE 3-2: DEPLETION DATES FOR ALTERNATIVE IMPORT AND NATIONAL STOCKPILE SCENARIOS (2004-2020)

	Base and Alternative Cases	Average Annual Requirements Growth				
		-4%	1%	6%	11%	16%
0	Base Case	May 2010	Apr 2009	Jul 2008	Feb 2008	Aug 2007
1	Import 25,000 pounds/year and Release No NDS HPP	2020+	Sep 2014	Jul 2011	Oct 2009	Nov 2008
2	Import 25,000 pounds/year and Release 70 percent of NDS HPP	2020+	2020+	Oct 2015	Nov 2012	Jul 2011
3	Import 25,000 pounds/year and Release All NDS HPP	2020+	2020+	Jun 2017	Apr 2014	May 2012
4	No Imports but Release 70 percent of NDS HPP	May 2019	Jun 2014	Apr 2012	Nov 2010	Mar 2010
5	No Imports but Release All NDS HPP	2020+	Jul 2016	Aug 2013	Feb 2012	Nov 2010
6	Import up to 50,000 pounds/year and Release No NDS HPP	2020+	Nov 2014	Oct 2013	Aug 2010	Nov 2008
7	Import up to 50,000 pounds/year and Release 70 percent of NDS HPP	2020+	2020+	Aug 2019	Jul 2014	May 2012

Source: Institute for Defense Analyses

DIFFERENT DEMAND GROWTH RATES

Table 3-2 also indicates the effects of lower demand growth rates for the entire period from 2004 to 2020 in the second and third columns and higher growth rates in the fourth and fifth columns. The highlighted column in the middle facilitates comparison of these results with the standard six percent growth rate. With slower growth than 6 percent per year, beryllium input supplies last longer and depletion is delayed. When growth is limited to 1 percent per year (second column), supplies last at least until 2014 for every alternative supply case, including those without imports. When demand declines by 4 percent per year, supplies last at least until 2019 for every alternative supply case. Clearly, slower demand growth is beneficial from the perspective of avoiding supply shortfalls.[60]

[60] Note, however, that slower growth rates exacerbate the problem of using all available imports when they are restricted to use in AlBeMet production only. Such a limitation is reflected in Case 6 in Table 3-2 when growth is less than 6%.

On the other hand, if demand growth is faster than six percent for the entire 17-year period, input supplies will be depleted sooner. As shown in the fourth column of Table 3-2, 11 percent growth advances the depletion date by two-to-three years for most supply cases. However, even without imports, Case 5 indicates that if DoD is willing to employ all the NDS reserve of billets, beryllium supply will not be depleted until 2012, allowing almost an eight-year period for selection and implementation of a long term solution. Assuming an even more adverse 16 percent annual growth rate displayed in the fifth column of the table, the results for Case 5 with no imports suggest that NDS inventories would not be depleted for six and a half years, a period which still could possibly be sufficient to design, permit, and build a new domestic production facility although time available for feasibility studies of a new manufacturing technology would be somewhat limited. Note, however, that the average historical growth rate for all forms of beryllium starting from 1941 has been only 2.7 percent.

Growth Rates That Change after 2009

Table 3-3 is similar to Table 3-2 except that the growth rates displayed across the top of the table in the second and third and fourth and fifth columns take effect starting in 2010. In other words, the six percent growth rate is maintained through 2009 before a lower or higher growth rates takes effect. The middle column highlighted in yellow allows the reader to compare the results to the standard six percent growth rate for the entire 17-year period. In most cases, variations in the post-2009 growth rate have only a modest impact on depletion dates, which are determined primarily by the common 6 percent growth rate assumed through 2009. In the most adverse cases (Cases 1 & 4) with 16 percent growth rate after 2009, there would still be about seven years to implement a long term solution if imports are available or some of the NDS billets are released for sale.

TABLE 3-3: DEPLETION DATES FOR ALTERNATIVE 2010-2020 GROWTH RATES

	Base and Alternative Cases	Average Annual Requirements Growth				
		-4%	1%	6%	11%	16%
0	Base Case	Jul 2008	Jul 2008	Jul 2008	Jul 2008	Jul 2008
1	Import 25,000 pounds/year and Release No NDS HPP	Sep 2011	Aug 2011	Jul 2011	Jun 2011	May 2011
2	Import 25,000 pounds/year and Release 70 percent of NDS HPP	2020+	Sep 2017	Oct 2015	Oct 2014	May 2014
3	Import 25,000 pounds/year and Release All NDS HPP	2020+	2020+	Jun 2017	Nov 2015	Apr 2015
4	No Imports but Release 70 percent of NDS HPP	Sep 2012	Jun 2012	Apr 2012	Feb 2012	Nov 2011
5	No Imports but Release All NDS HPP	Sep 2014	Mar 2014	Aug 2013	Apr 2013	Feb 2013
6	Import up to 50,000 pounds/year and Release No NDS HPP	2020+	Nov 2015	Oct 2013	Nov 2012	Sep 2012
7	Import up to 50,000 pounds/year and Release 70 percent of NDS HPP	2020+	2020+	Aug 2019	Nov 2016	Sep 2016

Source: Institute for Defense Analyses

SUMMARY OF MODEL RESULTS

Overall, the results of varying both supply and demand assumptions in Table 3-2 and Table 3-3 suggest that there should be sufficient time to select and implement a long-term solution to the beryllium supply problem even if it involves R&D on a new primary beryllium production process and designing, permitting, construction, equipping, and testing of a new primary beryllium plant. However, unless the demand for beryllium drops significantly in the short-run and/or imports become available for high purity applications soon, feasibility studies for a new production technology for primary beryllium will have to proceed expeditiously to leave enough time to implement whatever long-term solution to the beryllium metal supply problem is selected.[61]

[61] A recent reassessment of the rate at which BWI is consuming NDS beryllium ingots in its production process indicates that it is using them at a significantly faster rate than projected for 2004 and that this is likely to continue through 2005. Apart from some unanticipated sales, the increase in consumption rate of ingot appears to be due to a temporary increase in the metal to scrap ratio in the production process because of a temporary shortage of scrap and the unique properties of the beryllium being produced for the Webb Telescope. However, this increased burn rate for NDS ingot in the short run is not expected to significantly affect the long term projections for supply depletion in this report since recent feedback from some Federal Government program offices indicates the increased burn rate will be partially offset by reduced projections of beryllium consumption over the next five years in some other programs.

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Chapter Four: Policy Options and Recommendation

The analyses in the previous chapters of this study confirm that beryllium metal is needed for a wide variety of current and planned critical defense applications for both strategic and tactical systems including those that are essential to transformational warfare involving information technology and network-centric principles. Indeed, the six percent average annual increase in beryllium demand from 2000-2003 is likely to persist at least until 2008. Moreover, the National Defense Stockpile (NDS) beryllium ingot inventories currently committed for sale to BWI could be depleted as soon as 2008 if anticipated imports prove unreliable–by 2011 if imports are reliable. Note that the current purity levels of foreign supplies will not allow for their use in the majority of defense applications since they require high purity beryllium. This situation poses considerable risks to programs requiring beryllium in the foreseeable future because of the absence of a domestic primary beryllium source with BWI's facility mothballed and insufficient quality of imports. The release of NDS billets not yet authorized for sale would only extend the depletion date by a few years at most if they were made available for sale.

Faced with this situation, the Department of Defense must develop both a long-term solution to the beryllium supply problem and an interim solution that is flexible enough to deal with some uncertainties about when depletion of current supplies will actually occur and when the long-term solution will prove feasible and can be fully implemented.

Long-Term Solutions

There are three broad approaches to the beryllium metal supply problem that have been suggested given the most likely time frame of eight years before NDS feedstock runs out at current demand rates: (1) authorize BWI to transfer beryllium manufacturing technology to the Kazakhstan producer to increase the purity levels of the Ulba product, risking dependence on a single foreign supplier; (2) rely primarily on a crash R&D program to find replacements for high purity beryllium in defense applications; and (3) authorize a Federal Government cost share program with private industry for the design, construction and equipping of a new domestic primary beryllium metal facility as well as R&D funding on the feasibility of more efficient manufacturing technologies.

Foreign Dependence Based on Transfer of Manufacturing Capability

The first option, technology transfer followed by total dependence on a single source of imports, is unattractive for several reasons. To be sure, the U.S. is dependent primarily on imports for the feedstock for some other strategic materials such as cobalt and chromium which have had multiple reliable foreign sources for decades. However, placing the U.S. in a situation where the nation is totally dependent on beryllium metal ingots from Kazakhstan with China as an unlikely back-up poses serious risks, given the material's criticality in many strategic and tactical programs.

National Defense Stockpile ingots is depleted—the reliability of imports for at least non-high purity applications and future demand for beryllium over the next five to seven years. If NDS ingot is about to be exhausted before a new facility comes on line, the depletion date of beryllium feedstock should be delayed by authorizing DoD to release for sale some of the NDS reserves of the high purity billets current held for DOE and DoD emergencies. This study has demonstrated that there is sufficient NDS billet to meet likely DoD and even emergency DOE needs on an annual basis for several years. However, DOE staffers have rightly expressed concern that the NDS billet inventories ideally should not be used unless a new plant has completed the permitting stage and is within a year or two of coming on-line.

Even if some NDS billet must be released, a prudent reserve of the billets should be maintained, at least initially, sufficient to meet potential DOE contingencies. The prudent reserve that would not be offered for sale initially would be based on DOE's likely ability to consume beryllium during a period starting with identification of an emergency and ending with the establishment of U.S. access to newly produced beryllium metal.[48]

[48] An alternative way to release NDS billets during an interim period would be to ration their release for only the most critical defense-related needs.

FEDERAL COST SHARE FOR NEW PRODUCTION FACILITY

Given the risks and costs associated with the other options, a DoD cost share program with private industry to build a new domestic production facility is the most attractive alternative.[62] BWI has noted that although its sales of beryllium metal are now profitable at the divisional level, continued sales of beryllium in the expected $30 to $40 million range at operating profits of $5 – 6 million per year will not be sufficient for its parent company, Brush Engineered Materials (BEM), to fund a new primary metal plant. Hence, the Government would have to cost share such a facility. This financial assessment is realistic based on the parent firm's recent performance.

Government financial support for a new production facility involves a two-step process. First, an incremental R&D effort not to exceed $5 million could determine whether the potentially more cost-effective and occupationally safer electrolytic de-oxidation (EDO) manufacturing technology (or some other newer technology) is feasible for beryllium. The EDO process could provide important advantages including significantly lower construction and operating costs. Industry should be challenged to complete the R&D in three years to allow for design, permitting, and construction of a new facility in a faster timeframe than projected depletion of current beryllium feedstocks.

Second, pending initial findings from the aforementioned R&D effort, the DoD should prepare to initiate a multi-year program of $30 to $45 million (i.e., $6 to $9 million/year) in a cost share arrangement with private industry, possibly through Title III of the Defense Production Act, for new domestic production capacity based on the best available manufacturing technology. It is unlikely that private sector investment alone will occur without Government cost sharing. The first year of funding should be for the initial plant design options while the R&D on manufacturing technology is proceeding.[63] If the EDO technology is feasible, construction and equipment costs could be significantly less.

TRANSITION PERIOD

As this study has made abundantly clear, there are two key factors that could affect the length of the transition period until current feedstock of high purity beryllium from

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[62] Re-starting metal production at the mothballed 40-year-old facility is a short-term option but only for a national emergency given its economic inefficiency and the occupational health risks posed by the facility. While incremental improvements have been made over the years, the facility was designed well before current regulations were established to protect health, safety, and the environment. According to BWI, at the time the facility was mothballed it was concerned about relatively high rates of beryllium sensitization among BWI employees even though it was operating in compliance with the OSHA workplace air standard for beryllium. As of this writing, that standard has not changed. However, BWI expects that it will be able to meet a tighter standard and is already operating at an order of magnitude below the current standard in the parts of its plant that are still operating.

[63] This report does not constitute a formal request for budget authority or appropriations to implement its recommendations.

National Defense Stockpile ingots is depleted—the reliability of imports for at least non-high purity applications and future demand for beryllium over the next five to seven years. If NDS ingot is about to be exhausted before a new facility comes on line, the depletion date of beryllium feedstock should be delayed by authorizing DoD to release for sale some of the NDS reserves of the high purity billets current held for DOE and DoD emergencies. This study has demonstrated that there is sufficient NDS billet to meet likely DoD and even emergency DOE needs on an annual basis for several years. However, DOE staffers have rightly expressed concern that the NDS billet inventories ideally should not be used unless a new plant has completed the permitting stage and is within a year or two of coming on-line.

Even if some NDS billet must be released, a prudent reserve of the billets should be maintained, at least initially, sufficient to meet potential DOE contingencies. The prudent reserve that would not be offered for sale initially would be based on DOE's likely ability to consume beryllium during a period starting with identification of an emergency and ending with the establishment of U.S. access to newly produced beryllium metal.[64]

[64] An alternative way to release NDS billets during an interim period would be to ration their release for only the most critical defense-related needs.

APPENDIX A

KEY PLANNED BERYLLIUM METAL APPLICATIONS

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APPENDIX A: KEY PLANNED BERYLLIUM METAL APPLICATIONS

This Appendix provides extensive documentation on the specific systems (largely defense-related) that are projected to be the basis for the major new demand for beryllium metal in the foreseeable future. These systems are grouped into four major categories: Forward looking infrared radars (FLIRs), missile defense, and space (military, NASA, and commercial). The description of these systems will document the critical role that beryllium metal plays in achieving DoD's transformational warfare objectives. Moreover, by tracking over time the procurement budgets for these systems and their final decisions on use of beryllium metal, the reader will be better able to gauge whether the total annual demand for beryllium metal is likely to slow down, remain stable, or continue to grow.

FLIR Applications

Forward-looking infrared (FLIR) sensors are among the major defense applications for beryllium metal. FLIRs are typically included in modern targeting and navigation subsystems for military aircraft. They provide infrared images that enable pilots to identify targets and navigational features even in low-light conditions. Altogether, FLIRs may account for around 25 percent of defense-related demand for beryllium metal.

Aircraft FLIRs take advantage of the stiffness, dimensional integrity, and low weight of beryllium metal for use both in substrates for sensors and for their supporting structures. It is essential to avoid vibration and structural distortions that can reduce the clarity of infrared images. Emerging third-generation FLIRs are designed to enable aircraft to stand off further from the target and require even greater stability to provide clear magnified images. This should reinforce the utility of beryllium metal in FLIRs but the material is already employed in almost all fielded FLIR systems.

Table A-1 lists many of the key systems and subsystems currently in development or production that include FLIRs.[1] The list identifies the aircraft platforms on which the targeting subsystems will be used. Clearly, FLIRs are essential enablers for platforms with precision-strike capabilities. A pattern of generational transitions is also apparent in the table. Of course, new targeting subsystems are being developed for new aircraft, such as the F/A-18E/F Super Hornet, F/A-22 Raptor, F-35 Joint Strike Fighter, and RAH-66 Comanche. However, at the same time, new targeting systems also are being developed for upgrades to existing aircraft, such as the F-15E Strike Eagle, the F-16C/D Fighting Falcon, and the AH-64D Apache Longbow. As requirements and technology evolve, FLIRs are being replaced more frequently than aircraft.

[1] For an introductory survey of FLIR-using systems, see Greg Goebel, "Targeting Pods & Smart Shells," www.vectorsite.net/twbomb.html. Note that the Damocles is included here as a potential consumer of U.S.-produced beryllium metal but the subsystem is not in U.S. military use.

TABLE A-1: CURRENT AND FUTURE SYSTEMS WITH FLIRs	
LANTIRN (low altitude navigation and targeting infrared for night)	
	Used on F-15E, F-16C/D, and F-14D (targeting only), by Lockheed Martin
	FLIRs in both targeting pod (AN/AAQ-14) and navigation pod(AN/AAQ-13)
	Upgraded version with Sniper technology currently in production
Sniper XR (extended range targeting pod)	
	To replace LANTIRN on F-16s and F-15Es
	Developed by Lockheed Martin, technology used in other Lockheed systems
	Deliveries began in March 2003
F-22 (internally integrated targeting and navigation system)	
	Developed by Lockheed Martin
	Currently in low rate initial production phase
JSF EOTS (electro-optical targeting system)	
	For F-35 Joint Strike Fighter developed by Lockheed Martin
	Includes FLIR and other modules from Sniper XR carried internally and thermal imaging system with infrared cameras fitted at multiple locations
	Currently in system development and demonstration phase
NiteHawk (navigation infrared targeting equipment (AN/AAS-38 (A and B))	
	Used on F-18C/D, developed by Lockheed Martin
	Block 3 upgrade uses infrared array technology from Sniper
ATFLIR (advanced technology FLIR)	
	Replaces NiteHawk on F/A-18C/D and F/A-18E/F Super Hornet, by Raytheon
	In low rate initial production, scheduled for Block 2 F/A-18E/F starting in 2003
Damocles (French targeting pod with latest FLIR)	
	For use on Mirage 2000s, Super Etendard, and Dassault Rafale
	Developed by Thales (Thomson-CSF)
Litening ER (extended range targeting pod)	
	Used on some Harrier IIs, USAF Reserve and Air National Guard F-16s
	Replaced some LANTIRNs on F-15s until Sniper XR entered service
	Developed by Rafael of Israel, sold by Northrop Grumman
Arrowhead (new nose-mounted targeting and night vision system)	
	Replaces AH-64 Apache TADS (AN/ASQ-170)
	FLIRs for both targeting and pilot night vision sensor, by Lockheed Martin
	Scheduled to enter service in 2004
EOSS (electro-optics sensor system)	
	For RAH-66 Comanche, being developed by Lockheed Martin
	FLIRs included in TADS and also in pilot night vision system
Hawkeye XR TSS (target sight system) (AN/AAQ-30)	
	For re-manufactured AH-1Z SuperCobra helicopter gunship for Marines
	By Lockheed Martin, using Sniper staring focal plane array FLIR
	Now completing engineering and manufacturing development phase
Predator (RQ-1A)	
	Developed by General Atomics, includes FLIR
	In production since 1997
Global Hawk (RQ-4A)	
	Includes Raytheon infrared sensor system with 10-inch reflecting telescope
	May upgrade via spectral infrared remote imaging transition testbed (SPIRITT)
	In low rate initial production phase
Source: Institute for Defense Analyses	

Figure A-1 illustrates planned DoD procurement schedules for a number of subsystems with FLIRs that are expected to use beryllium.[7] These schedules reflect the maturity of the subsystems and especially the schedules for procuring new or upgrading existing aircraft. In several cases, either the aircraft or the targeting subsystem is still in development so procurement was not expected to begin until 2004 or later. For the first six aircraft shown, planned FLIR procurement will be completed during the next ten years, although subsequent procurement is possible in some cases.[8] For the last three systems, in contrast, the majority of procurement is planned to occur after 2010. Overall, Figure 5-1 indicates that there will be continuous requirements for FLIRs and for the beryllium metal on which most FLIRs rely.

FIGURE A-1: PROJECTED PROCUREMENT SCHEDULES FOR FLIRs

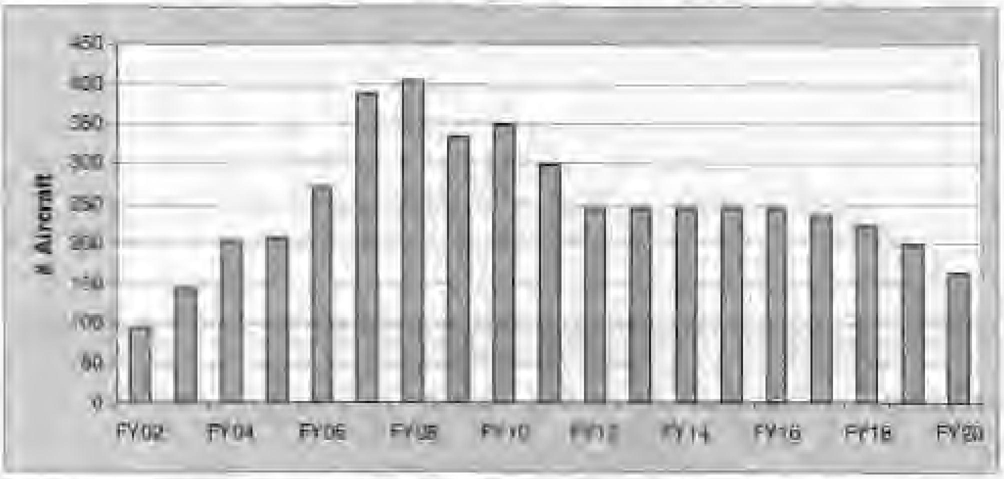
Source: Institute for Defense Analyses

Figure A-2 illustrates the procurement schedules on Figure 5-1 from a different perspective showing the number of aircraft platforms that will require FLIRs each year. Procurement grows strongly through 2008 at a trend rate of 24 percent per year. Thereafter, procurement declines at a trend rate of -5 percent per year. By 2020, however, the number of platforms is still some 70 percent higher than the number in 2002. Of course, the figure offers only a rough indication of the potential requirement for beryllium metal. For example, it does not reflect differences in the amount of beryllium needed for the various FLIRs. Still, the figure does suggest a substantial future market.

[7] The figure is based mainly on Department of Defense, "Defense Budget Materials: FY 2004 Budget," www.defenselink.mil/comptroller/defbudget.

[8] For example, planned procurement of the Arrowhead for the AH-64D upgrade covers less than half of the aircraft so there is room for additional purchases, depending on the progress of the RAH-66. Also, plans for Predator procurement beyond FY 2000 remain "to be decided."

FIGURE A-2: PROJECTED PROCUREMENT QUANTITIES FOR FLIRS



Source: Institute for Defense Analyses

Missile Defense Applications

The Ballistic Missile Defense System is a growing consumer of beryllium. There is a strong requirement for infrared and optical sensors that can detect and track missile threats and beryllium has already been used for a number of missile defense systems. As with FLIR applications, beryllium is used both for sensors and for supporting structures. While only one missile defense application ranks in the top ten for quantities of beryllium recently consumed for defense-related applications, much larger volumes may be required in the longer-range future. For the most part, missile defense systems are still evolving in development and test programs. The most substantial procurement is likely to occur after the present decade.* Following are a few examples of missile defense systems likely to use beryllium.

The Ground-Based Interceptor (GBI) is designed for use against intermediate- and long-range missile threats. The GBI includes a booster missile and an exoatmospheric kill vehicle (EKV) that must track and collide with hostile targets. The EKV is equipped with a very sensitive long-range electro-optical infrared seeker that uses beryllium. Up to 20 GBIs will be procured as part of the initial defensive capability to be deployed starting in FY04. Interceptor development for various basing modes will continue through FY10 and beyond and it is not clear whether more GBIs will be procured in the coming decade.

* The Missile Defense Agency, like some other DoD components before it, is attempting to limit use of beryllium where possible because of health hazards. In 2002, for example, the agency solicited proposals for the identification and demonstration of substitute materials that could offer the desirable or most critical benefits of beryllium without the associated health hazards. See www.dodsbir.com/solicitation/mda031
htm.

The SM-3 missile, whose seeker uses beryllium, will also be deployed beginning in FY04. It is designed to provide defense against medium-range missiles. Current plans for FY04 call for ordering up to 20 SM-3 missiles for installation on three Aegis cruisers.

The Patriot PAC-3 is designed to counter short- and medium range missile threats.[7] This system, which uses AlBeMet for electronic substrates, is currently at the low-rate-initial-production stage. Procurement of nearly 1000 PAC-3 missiles is planned for the FY03-09 period. There is also potential for future procurement of Theater High-Altitude Area Defense (THAAD) terminal phase missiles, but the program currently remains in the engineering development phase and procurement quantities have not been established. The THAAD uses beryllium in an optical bench structure.

The Airborne Laser system deploys a powerful laser aboard a converted Boeing 747-400F aircraft. The system includes the Airborne Laser Infrared Search and Track sensor to detect and track threat missiles, especially during their initial boost stage. Beryllium is used in structures that stabilize the optical sensors. The program, which is in the concept development phase, has modified and tested one demonstration aircraft and will begin modification of a second one in FY2005. Current plans call for seven aircraft, but most of these will be procured after 2010. Weight reduction has been a key issue and the system makes use of composites and some beryllium.

Space-based infrared and optical sensors are also candidates for beryllium use, although only a limited number of satellite launches are planned for the program by 2010. In FY07, two test satellites with infrared and visible sensors are planned for launch to low-earth orbits. These are part of the Space Tracking and Surveillance System (STSS). An improved STSS satellite will be launched around 2010. In addition, 3-to-5 satellites will be launched beginning in FY08 to support testing of the space-based kinetic energy interceptor. For the Space-Based Infrared System-High (SBIRS-High) warning system, two out of a planned five satellites are being manufactured now, with the first launch set for FY2007. In addition, the first of two SBIRS sensors that will be launched on non-SBIRS host satellites is scheduled for delivery this year. The SBIRS-high program, which is in the development phase, uses some beryllium.

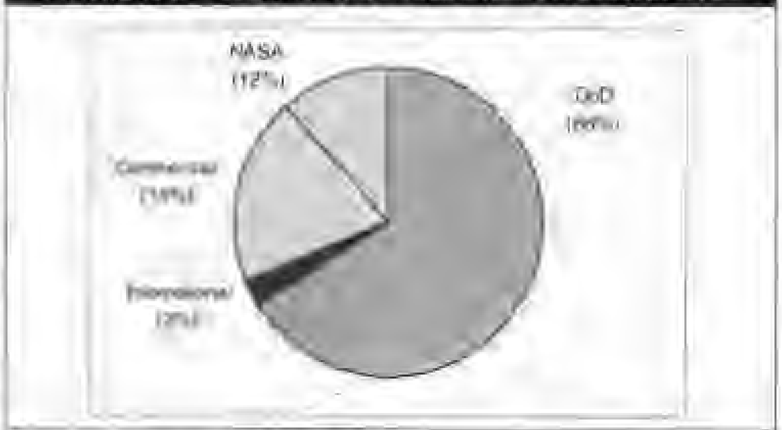
Space-Related Applications

Satellites and other spacecraft are used extensively to support both defense and civilian needs. They are used for communication as well as observation of the earth, its weather and environment, human activity, and the far reaches of the universe. Beryllium metal is used widely in space because its light weight helps limit expensive launch costs.[8] Due to its stiffness and other properties, it is used

[7] Israel's Arrow missile system, which targets theater ballistic missiles, also uses beryllium.
[8] It can cost $10,000 or more to launch a lb of material to geosynchronous orbit, so using beryllium rather than a cheaper but heavier material may be the less costly alternative. See, for example, the orbit cost comparison at www.peregrinecrop.com/peregrine/orbit.htm. See also the historical launch cost data at http://www.jsc.nasa.gov/bu2/launch.html.

for structures, electronic housings and heat sinks, and especially for sensors and sensor supports. As indicated on Figure A-3, which illustrates satellite consumption shares for beryllium metal during 2000-2002, DoD accounted for nearly two-thirds of the satellite requirements. NASA and commercial entities also made substantial use of beryllium for satellites.[7] The split of beryllium consumption between pure metal and AlBeMet was 70:30 for DoD, 50:50 for NASA, and 4:96 for commercial users, suggesting that DoD has the most demanding applications for high purity material. The following three sections discuss space applications for DoD, NASA, and commercial users.

FIGURE A-3: BERYLLIUM CONSUMPTION FOR SATELLITES



Source: Institute for Defense Analyses

Military Space

A number of military satellite programs make use of beryllium metal. While the number of satellites launched each year is relatively small, it is clear that modernization and replenishment needs will ensure a continuing demand for satellites and the beryllium they utilize for structures, electronic housings and heat sinks, and especially for sensors and sensor supports. Increasing reliance on satellites for military operations may support long-term growth in beryllium requirements. The following paragraphs describe specific satellite programs that employ or will employ beryllium metal.

MILSTAR is an existing military communications system designed to provide military-unique features and connectivity for both tactical and strategic purposes. The five satellites that constitute the MILSTAR constellation were launched during the 1994-2003 period. The future Advanced Extremely High Frequency (AEHF) communications satellites will replenish the MILSTAR constellation, adding enhanced capabilities. Two AEHF satellites are being built now in the program's system development and demonstration phase. Fabrication of the first satellite for the procurement phase will begin in FY2006. The AEHF program is a cooperative effort that includes Canada, the UK, and The Netherlands.

In another communications program, Wideband Gapfiller Satellites (WGS), DoD will procure satellites to address a current gap in the high data rate capabilities needed for warfighter support. Three satellites have been ordered and are scheduled for launch during FY2005-2006. An additional two satellites will be ordered in FY2007-2008 and one may be ordered later. The WGS, which augments the existing Interim Wideband System, is being procured on a near-commercial basis using mainly existing commercial technology.

[7] The figure reflects beryllium produced in the U.S. and does not include beryllium produced in China or Kazakhstan, e.g., for use in foreign satellites.

The NAVSTAR Global Positioning System (GPS) provides radio navigation signals in support of a rapidly expanding list of military and civilian applications.[8] The GPS constellation includes 24 satellites with a design life of up to ten years (for Block IIR). To meet the need for replenishment and modernization, some 55 GPS satellites were procured between 1978 and 2000. Boeing currently has a contract to develop and produce GPS Block IIF satellites. DoD will order 10 of these during the FY2005-2008 period and additional undetermined quantities thereafter.[9] A modernization development effort is also in process.

The Defense Meteorological Satellite Program (DMSP) provides global weather data to support U.S. forces. It provides visible and infrared imagery and other environmental data. Over the years, some 45 satellites have been procured, including four that have not yet been launched. The follow-on to the DMSP is the National Polar-orbiting Operational Environmental Satellite System (NPOESS), a tri-agency program addressed below in the section on NASA requirements.

The Defense Support Program (DSP), which includes infrared sensors, provides strategic and tactical warning of ballistic missile attack. Some 19 DSP satellites have been launched to geosynchronous orbits over the years. The last two are in production now and are scheduled for launch beginning in FY2004. The follow-on program to DSP is the SBIRS, which is mentioned above in the discussion of ballistic missile defense.

The Navy's UHF Follow-on Satellite constellation provides UHF communications worldwide for DoD. Users include the Global Broadcast Service. Through 2003, 11 satellites were launched. The follow-on program is the Mobile User Objective System (MUOS) satellite effort. MUOS will eventually include nine satellites, with one to be procured each year from FY2005 to FY2013.

The National Reconnaissance Office (NRO) is a DoD agency that designs, builds and operates the nation's reconnaissance satellites. Its satellites support defense and intelligence monitoring, surveillance, and reconnaissance needs. Increasingly, imaging satellite capabilities are being integrated into military operations, for example, for reconnaissance and precision targeting. This will definitely cause a substantial increase in future requirements for imaging satellites, in both quantity and capability and therefore in beryllium consumption associated with them.

NASA

NASA accounted for about 12 percent of the beryllium metal used for satellites during 2000-2003. However, as noted below, a new NASA telescope program will substantially increase that share for a few years.

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[8] The GPS satellites also include sensors for the U.S. Nuclear Detonation Detection System.

[9] See "U.S. Military GPS 33 GPS Block IIF Satellites, USA," www.space-technology.com.

NASA makes use of beryllium in both satellites and exploratory spacecraft. For example, on the National Polar-orbiting Operational Environmental Satellite System (NPOESS), beryllium is used in the Cross-track Infrared Sounder (CRIS). NASA supports the tri-agency NPOESS together with the U.S. Air Force and the National Oceanic and Atmospheric Administration (NOAA). Two NPOESS satellites are scheduled for launch at the end of the decade to provide global weather information for DoD and civilian purposes, including studies of global environmental change. The number of additional satellite purchases remains to be determined.

One application that will have a significant impact on consumption in the short run is NASA's decision to use beryllium mirrors in the James Webb Space Telescope (JWST), which will replace the Hubble Space Telescope around 2011.[10] The JWST will take advantage of the light weight and the dimensional stability of beryllium metal, which was selected in competition with ultra-low expansion glass. It will be an extremely sensitive infrared telescope, designed to observe the first stars and galaxies formed in the universe. Its primary mirror will have a 6.5-meter aperture composed of 18 hexagonal beryllium segments. The diameter of the JWST will be 2.5 times that of the glass-mirrored Hubble, but the JWST will weigh only one-third as much. BWI will hot isostatic press (HIP) its advanced optical-grade O-30 spherical powder to fabricate the required shapes and expects to ship more than 11,000 lbs of beryllium during the 2004-2006 time frame.[11] This represents a substantial surge in NASA's beryllium consumption, which will drop back to a more modest level by 2007.

NASA also uses beryllium in its planetary exploration vehicles. For example, on the 1997 Mars Pathfinder rover, beryllium was used for the x-ray detector window. Beryllium is also used on two new Mars rovers, which were launched in June and July, 2003. The next version of the Mars rover will be launched in 2009. Beryllium is also used on the Mercury Laser Altimeter (MLA), which will include an infrared laser to measure the topography of Mercury. The Mercury MESSENGER spacecraft is scheduled for launch in March, 2004. Ion engines, which will power many future deep-space missions, also use beryllium.[12] For example, NASA's 2006 Dawn mission to orbit the Vesta and Ceres asteroids will use ion propulsion.

[10] See the announcement at www.ngst.nasa.gov/News.

[11] BWI expects to generate and recycle an unusually large share of inside scrap in order to meet the very demanding material requirements. A substantial amount of outside scrap will also be generated and returned to BWI for recycling.

[12] In October, 1998 NASA's Deep Space 1 mission was the first to use ion propulsion successfully. Under this approach, thrust is generated by escaping ions that are produced by electrically charging xenon gas. The thrust is weak but the engine consumes little fuel and can run for years. See Robert Roy Britt, "Moon Mission First for Europe, to Launch Saturday," www.space.com, September 26, 2003.

Commercial Space

Commercial satellites accounted for some 19 percent of the beryllium metal used for satellites in 2000-2002. Satellites also represented a significant share of the commercial market for beryllium, accounting for about 16 percent of overall commercial consumption. Most of the material used was in the form of AlBeMet rather than pure beryllium metal.

The global number of commercially launched satellites is projected to grow modestly over the coming decade, rising from about 24 in 2003 to 34 in 2012.[13] While growth will average about 4 percent per year, the number of new satellites launched in 2012 will nevertheless fall far short of the 1998 peak of 107 satellites. During the late 1990s, many new satellites were launched to relatively low non-geosynchronous orbit (NGSO) to provide direct communications services, e.g., Iridium. Those ventures, however, quickly became insolvent and no comparable launches are projected within the 2004-2012 period.

Some 75 percent of the projected NGSO satellites are considered scientific and the rest will provide commercial imaging services. U.S.-ownership is concentrated among the latter group and accounts for about 25 percent of all the projected commercial NGSO satellites.[14]

About 75 percent of projected commercial satellites will be launched to geosynchronous orbit (GSO) high above the earth. They will provide communications, imaging, meteorology, broadcasting, and other services.[15] Globally, some 65 percent of projected new GSO satellites are commercial while 17 percent are military and the remaining satellites will serve other national purposes.

Commercial satellites naturally serve mainly civilian users. In the U.S., for example, the Federal Government accounts for only about 10 percent of the revenue paid for commercial satellite services.[16] DoD nevertheless benefits greatly from the availability of commercial services. It routinely uses commercial satellites for communications that are not mission-critical and also to augment military-owned satellites. During Desert Shield/Desert Storm, for example, some 45 percent of communications between the U.S. and the Persian Gulf utilized commercial satellites. During Operation Joint Endeavor in Bosnia, one of the leased commercial satellite transponders was used to uplink live imagery from Predator unmanned aerial vehicles.[17] Since 2000, the Defense Information Systems Agency (DISA) has contracted for airtime services from the troubled Iridium satellite constellation. Recently, DoD's National Geospatial-Intelligence Agency (formerly the National Imagery and Mapping

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[13] Commercial satellite launches are projected in Federal Aviation Administration and Commercial Space Transportation Advisory Committee (COMSTAC), "2003 Commercial Space Transportation Forecasts," May 2003. These projections focus mainly on satellites that will be launched on commercial vehicles.

[14] The FAA/COMSTAC projection does not include military NGSO satellites.

[15] For several years, the average GSO satellite has grown in mass and number of transponders, although it is not clear that this trend will continue.

[16] See U.S. General Accounting Office, "Critical Infrastructure Protection: Commercial Satellite Security Should Be More Fully Addressed," GAO-02-781, August 2002, 6.

[17] See "Spacelink International and Defense Information Systems Agency (DISA)," www.[illegible]ss/press4.html.

Agency) also contracted with commercial firms for up to $1 billion in satellite imagery services.[18]

[18] In January 2003, NIMA concluded a three-year contract for up to $500 million in commercial satellite imagery from DigitalGlobe and a five-year contract for up to $500 million for worldwide imagery from Space Imaging. See Federal Aviation Administration and Commercial Space Transportation Advisory Committee (COMSTAC), "2003 Commercial Space Transportation Forecasts," May 2003, 39-42.