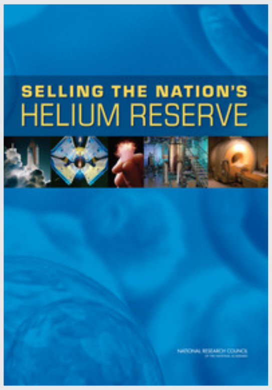

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SELLING THE NATION'S HELIUM RESERVE

Committee on Understanding the Impact of Selling the Helium Reserve

Board on Physics and Astronomy

National Materials Advisory Board

Division on Engineering and Physical Sciences

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Preface

In the public's mind, helium is the gas that fills balloons and the Goodyear blimp. Supply shortages or price structures that result in the loss of either helium-filled balloons or the Goodyear blimp would probably stimulate media coverage of the problem and generate some regret, but their loss would not impact national security or the public welfare. Interestingly, it was lighter-than-air use—to supply airships—that motivated the creation of the Federal Helium Reserve back in 1925. This report deals principally with those lesser-known but essential uses of helium that have evolved, along with the technology, to become of critical importance to the nation's research, space, medical, and defense programs. It follows the National Research Council (NRC) report released in 2000[1] that assessed the impacts of the Helium Privatization Act of 1996 by which Congress directed the government to sell essentially all of the helium reserve to compensate it, the government, for its investment in the helium and in the helium's storage infrastructure. Changes in price and availability since that NRC study have caused concerns about the availability of helium to critical users and raised questions about the previous report's conclusion that the sale of the helium reserve would not significantly affect helium availability.

The NRC convened the Committee on Understanding the Impact of Selling the Helium Reserve to determine whether selling off the U.S. helium reserve in the manner prescribed by law has had any adverse effect on U.S. scientific, techni-

[1]NRC, *The Impact of Selling the Federal Helium Reserve* (Washington, D.C.: National Academy Press, 2000).

cal, biomedical, and national security users of helium. The Board on Physics and Astronomy (BPA) and the National Materials Advisory Board (NMAB) developed the charge for this study in consultation with the study's sponsors at the U.S. Department of the Interior's Bureau of Land Management. The complete charge is reproduced in Appendix A.

The full committee met in person four times (see Appendix C) to address its charge. It formed subgroups to study specific areas in further detail and to develop the text of the final report. At its meetings, the committee heard from members of the communities involved in all the aspects of helium handling, from its extraction from underground reservoirs and its various stages of purification to its delivery and use by the end users. The work of the committee between meetings relied upon conference calls and e-mail correspondence. This final report reflects not only the committee's concerns about how the helium reserve is being managed but also its considered opinion on how it should be managed in the future.

The committee that prepared this report is composed of representatives from the many disparate communities that use helium, experts able to address the intricate economic issues that arise in assessing the helium markets, as well as representatives from industry (see Appendix B for biographical sketches of the committee members). In the course of its deliberations, members of the committee, scientists and non-scientists alike, were struck by the inordinate impact that increases in helium prices and its periodic scarcity are having on the small-scale science community. Unless structural changes are adopted that would allow members of this community to avail themselves of the existing so-called in-kind program, continued price increases and scarcities may result in these programs losing significant research capability, which in turn may have long-term impacts for the nation from the loss of both research results and the future researchers who would otherwise be receiving training. The committee believes that with clear guidance and measured responses, the helium reserve will be able to support the many critical users of helium in the United States for years to come. As it notes changes in conditions not anticipated in the 2000 Report, the committee advocates the establishment of an ongoing mechanism for monitoring the supply situation and the availability of helium to priority users.

As committee co-chairs, we are especially grateful to the committee members for their wisdom, cooperation, and commitment to ensuring the development of a comprehensive report. The capable and energetic support provided by BPA and NMAB staff members Michael Moloney and James Lancaster was essential to completion of the study and this report.

Charles G. Groat, *Co-Chair*
Robert C. Richardson, *Co-Chair*
Committee on Understanding the Impact of Selling the Helium Reserve

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Gordon Baym, University of Illinois at Urbana-Champaign
John Curtis, Colorado School of Mines
Robert Dynes, University of California at San Diego
Donald Gessaman, EOP Group, Inc.
William Halperin, Northwestern University
Charles Howe, University of Colorado
Carl Johnson, Pipeline and Hazardous Materials Safety Administration (retired)
Robert Kephart, Fermilab
Jane Long, Lawrence Livermore National Laboratory
Chris Sims, Princeton University
G.J. Wasserburg, California Institute of Technology

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Julia Phillips, Sandia National Laboratories. Appointed by the National Research Council, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Executive Summary

Helium has long been the subject of public policy deliberation and management, largely because of its many strategic uses and its unusual source—it is a derived product of natural gas and its market has several anomalous characteristics. Shortly after sources of helium were discovered at the beginning of the last century, the U.S. government recognized helium's potential importance to the nation's interests and placed its production and availability from federally owned mineral interests under strict governmental control. In the 1960s, helium's strategic value in cold war efforts was reflected in policies that resulted in the accumulation of a large reserve of helium owned by the federal government. The latest manifestation of public policy is expressed in the Helium Privatization Act of 1996 (1996 Act), which directs that substantially all of the helium accumulated as a result of those earlier policies be sold off by 2015 at prices sufficient to repay the federal government for its outlays associated with the helium program.[1] The present report assesses whether the interests of the United States have been well served by the 1996 Act and, in particular, whether selling off the helium reserve "has had any adverse effect on U.S. scientific, technical, biomedical, and national security users of helium." [2]

[1]Although the 1996 Act directs that substantially all federally owned helium be sold by 2015, sales efforts to date have fallen short of the act's directive, and significant amounts of helium will remain after the mandated sell-off deadline. This presents its own set of issues, which are briefly discussed at the end of the Executive Summary.

[2]Statement of task—see Appendix A.

In response to its charge, the committee finds that selling off the helium reserve, as required by the 1996 Act, has adversely affected critical users of helium and is not in the best interest of U.S. taxpayers or the country. The committee recommends several ways to address the outstanding issues. Several of its recommendations respond to the very large impact that selling off the reserve has had and is continuing to have on the helium market in general. The amount of federally owned helium being sold is enormous: it is currently equivalent to approximately one-half of U.S. helium needs and almost one-third of global demand. One consequence is that the price of federally owned helium, which is set not by current market conditions but by the terms of the 1996 Act, dominates, if not actually controls, the price for crude helium worldwide. The committee recommends that procedures be put in place that open the price of federally owned helium to the market.

Another of the committee's concerns is that the drawdown schedule required by the 1996 Act, which dictates that the reserve helium be sold on a straight-line basis—the same amount must be sold each year until the reserve is substantially gone—is a wasteful way to draw down a reservoir. Because it is much more costly and more likely to leave significant amounts of helium unrecoverable than alternative drawdown scenarios, the committee recommends that this portion of the 1996 Act be revisited. In addition, given recent developments in the demand for and sources of helium (the principal new sources of helium will be in the Middle East and Russia, and if the sell-down continues, the United States will become a net importer of helium in the next 10 to 15 years), the committee recommends that Congress reconsider whether selling off substantially all federally owned helium is still in the nation's best interest.

The committee also addresses the needs of small-scale government-funded researchers who use helium, a group that has been hit particularly hard by sharp price rises and shortages that have characterized the helium market in recent times. This group was singled out mainly because such research is an important public enterprise and the funding mechanisms available to the researchers, typically grants on 3-year cycles for set amounts, do not allow them to respond to short-term fluctuations. These research programs should have some protection from the instabilities recently characterizing the helium market. Accordingly, the committee recommends that the researchers be allowed to participate in an existing program for government users of helium that would give them priority when there is a helium shortage; it also recommends that funding agencies help such researchers to acquire equipment that would reduce their net helium requirements. Implementing these recommendations would not subsidize such users nor would it require significant additional outlays: Indeed, over time, it would lead to the much more efficient use of the federal funds with which helium is purchased. The remaining conclusions and recommendations consist of steps to help properly manage the helium reserve and to develop and implement a plan that would protect this important national resource.

Finally, while noting that the question of how critical helium users in the United States will be assured a stable supply of helium in the future is beyond the scope of its charge, the committee points out that several important issues related to this topic remain unanswered. How will the large amounts of federally owned helium that remain after the mandated sell-off deadline in 2015 be managed after that date? Moreover, from a wider perspective, should a strategic helium reserve be maintained? These questions need to be answered in the near future, well before most federally owned helium is sold.

Summary

Ready access to affordable helium is critical to many sectors in academe, industry, and government. Many scientists—from individuals engaged in small-scale cryogenic research to large groups using high-energy accelerators and high-field magnets—rely on helium to conduct their research, and because the federal government supports many of these researchers, it has a direct stake in their continued success. The medical profession also depends on helium, not only for biological research in devices such as superconducting quantum interference devices (SQUIDS), but also for diagnosis with tools such as magnetic resonance imaging (MRI) devices. Industrial applications for helium range from specialty welding to providing the environments in which semiconductor components and optical fiber are produced. Government agencies that require helium include the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), as only helium can be used to purge and pressurize the tanks and propulsion systems for NASA and DOD's rockets fueled by liquid hydrogen and oxygen. NASA and the Department of Energy (DOE) also use helium to support weather-related missions and various research and development programs funded by these agencies, both at government facilities and at universities. Finally, DOD must have ready access to helium to operate the balloon- and dirigible-based surveillance systems needed for national security.

The Federal Helium Reserve,[1] managed by the Bureau of Land Management

[1]The Federal Helium Reserve (also referred to here as the Helium Reserve or the Reserve) consists of (1) a naturally occurring underground structural dome near Amarillo, Texas, where federally owned

(BLM) of the U.S. Department of the Interior, is the only significant long-term storage facility for crude helium in the world and currently plays a critical role in satisfying not only our nation's helium needs but also the needs of the world. The federally owned crude helium now on deposit in the Reserve was purchased by the federal government as a strategic resource during the cold war. After the cold war, Congress enacted legislation (the Helium Privatization Act of 1996 referred to hereinafter as the 1996 Act) directing that substantially all of the federally owned helium in the Reserve be sold at prices sufficient to repay the federal government's outlays for the helium and the infrastructure, plus interest. The present report, called for by BLM, examines whether BLM's selling of this helium in the manner prescribed by law is having an adverse effect on U.S. users of helium and, if so, what steps should be taken to mitigate the harm.[2]

This report assesses the current status of the supply and demand for helium as well as the operation of the federal helium program. It concludes that current efforts to comply with legislative prescriptions have had and will continue to have negative impacts on the needs of both current and future users of helium in the United States. The sell-down of federally owned helium, which had originally been purchased to meet the nation's critical needs, is coming at a time when demand for helium by critical and noncritical users has been significantly increasing, especially in foreign markets. If this path continues to be followed, within the next 10 to 15 years the United States will become a net importer of helium whose principal foreign sources of helium will be in the Middle East and Russia. In addition, the pricing mandated by the 1996 Act has triggered significant increases in the price of crude helium, accompanied by equally significant increases in the prices paid by end users. Finally, the helium withdrawal schedule mandated by the 1996 Act is not

(and some privately owned) crude helium is stored (the Bush Dome Reservoir); (2) an extensive helium pipeline system running through Kansas, Oklahoma, and Texas that connects crude helium extraction plants with one another, with helium refining facilities, and with the Bush Dome Reservoir (the "Helium Pipeline"); and (3) various wells, pumps, and related equipment used to pressurize crude helium, to store and withdraw it from the Bush Dome Reservoir, and to operate other parts of the Federal Helium Reserve. As of this writing in late 2009, the Federal Helium Reserve contained slightly more than 18 billion cubic feet of federally owned helium, with a value of approximately $1.2 billion using BLM's current posted price of $64.75 per thousand cubic feet.

[2]As discussed more fully in the section of Chapter 1 entitled "Review of the 2000 Report's Conclusions," the 1996 Act called for an Academy study to determine if such disposal would have a substantial adverse effect on U.S. interests. That study, *The Impact of Selling the Federal Helium Reserve*, published by the NRC in 2000 and referred to hereinafter as the 2000 Report, concluded that the 1996 Act would not substantially affect matters. While several of that study's findings remain valid, it did not correctly predict how the 1996 Act would impact prices or how the demand side of the helium market would grow, in part a response to the ready availability of helium arising from the sell-off of the Helium Reserve pursuant to the 1996 Act. These factors have significantly impacted the current market for helium.

an efficient or responsible reservoir management plan. If the reserve continues to be so managed, a national, essentially nonrenewable resource of increasing importance to research, industry, and national security will be dissipated.

FINDINGS AND RECOMMENDATIONS

Specific Recommendations for Immediate Improvements

To address these issues, the committee first lays out three specific recommendations for improving the federal helium program: changing the methods for pricing the helium being sold, committing more resources to managing the physical facilities at the Federal Helium Reserve, and providing assistance for small-scale scientists by expanding the sales program for government users to include them and promoting conservation and reuse by these users.

Pricing Mechanism

The 1996 Act set minimum selling prices, adjusted for inflation, for crude helium held by the BLM such that the sale of that helium at those prices would generate sufficient revenue to repay the federal government for what it originally spent to purchase the helium and to build the supporting infrastructure, plus interest. BLM has elected to sell its helium at those minimum prices. At the time of the 1996 Act, the minimum selling price was almost double the price being paid for privately owned crude helium. A market that had been stable for several decades prior to the sell-off of federally owned helium, experiencing neither drastic price increases nor shortages of supply,[3] began to change after BLM started to sell its crude helium. Almost immediately, privately sourced crude helium prices began to rise, and those prices continued to steadily increase so that they now meet or exceed BLM's price, and many of the sales contracts for private helium expressly tie future selling prices to BLM's price. Thus this legislatively set price for federally owned helium is now setting the price for crude helium, and there is no assurance that this price has any relationship to the current market value of that helium.

To the extent BLM's price is lower than the price the market would otherwise set for crude helium, this pricing mechanism could have several negative consequences: (1) it could lead to inaccurate market signals, increased consumption, and accelerated depletion of the Federal Helium Reserve; (2) it could retard efforts to conserve and develop alternative sources of crude helium; (3) it could result in transfers of taxpayer assets to private purchasers at below-market values—that is,

[3]NRC, *The Impact of Selling the Federal Helium Reserve* (Washington, D.C.: National Academy Press, 2000), page 9.

it could amount to a taxpayer-financed subsidy for consumption of this scarce publicly owned resource; and (4) sales of federally owned crude helium could end up subsidizing exports of helium.

The managers of the Reserve should shift to a market-based pricing policy to improve the exploitation of this important national asset. The report notes that several mechanisms could be used to implement market-based pricing and thereby introduce competition, or the threat of it, to the process. However, one complicating factor is that before federally owned helium can be used, it must be refined, and the refining capacity linked to the Reserve is owned by four companies. The committee believes that market-based pricing of crude helium from the Reserve will require that purchasers other than those four companies have access to refining capacity linked to the Reserve. However, additional details on mechanisms to provide access to excess refining capacity and to attain the goal of market-based pricing of crude helium from the Reserve are beyond the committee's charge.

Recommendation. The Bureau of Land Management (BLM) should adopt policies that open its crude helium sales to a broader array of buyers and make the process for establishing the selling price of crude helium from the Federal Helium Reserve more transparent. Such policies are likely to require that BLM negotiate with the companies owning helium refining facilities connected to the Helium Pipeline the conditions under which unused refining capacity at those facilities will be made available to all buyers of federally owned crude helium, thereby allowing them to process the crude helium they purchase into refined helium for commercial sale.

Management of the Reserve

An additional aspect of the 1996 Act that has significant—and undesirable, in the judgment of this committee—implications for the overall management of the Helium Reserve is the Act's requirement that the sale of federally owned crude helium is to take place on a straight-line basis.[4] The mandated constant extraction rate conflicts with standard practices for the exploitation of this type of reservoir, which is that production rates vary over the economic life of a deposit, typically declining over time. Declining production rates and reservoir pressures delay

[4]The law directs that crude helium from the Reserve be offered for sale in such amounts as may be necessary to dispose of all helium in excess of 600,000,000 cubic feet on a straight-line basis between January 1, 2005 and January 1, 2015. Although BLM has offered helium for sale in the amounts required by the 1996 Act, not all such helium has been purchased and as a consequence significant amounts of federally owned helium will remain in the Federal Reserve after January 1, 2015. This is discussed in more detail in Chapter 5 in the section entitled "Sell-Down of Crude Helium Pursuant to 1996 Act."

encroachment of water from nearby aquifers and connected reservoirs, and promote the efficient drainage and recovery of the resource gas in place.

Recommendation. The BLM should develop and implement a long-term plan that incorporates appropriate technology and operating practices for delivering crude helium from the Federal Helium Reserve in the most cost-effective manner.

Assistance for Small-Scale Researchers

Among the events that triggered this study were the soaring prices and limited supplies that characterized the refined helium market in the fall of both 2006 and 2007. The committee, composed of individuals from a wide range of professions—economists, business people, and scientists—notes that small-scale scientists were particularly hard hit by price shocks and interruptions in the supply of refined helium during that time. An informal poll conducted by committee members of approximately 40 research programs at universities and national laboratories that use helium indicated that shortages of liquid helium interrupted the helium supply for almost half of these programs, with some interruptions lasting for weeks at a time during the late summer and fall of both 2006 and 2007. While anecdotal, these poll results provide clear indication that this community of users is directly impacted by general shortages of helium. For many of those scientists, losing access to helium, even temporarily, can have long-term negative repercussions for their research.

In general, the federal grant programs that support these researchers simply are not designed to cope with the pricing shifts and other market volatilities experienced here. The grants typically are for 2 or 3 years and for a set amount that does not adjust if a principal expense of research such as helium significantly increases. Further, the relatively short duration of such grants, with no guaranty of renewal, effectively precludes these research programs from entering into long-term contracts that might at least partially reduce the risk of significant price increases and shortages. Further, if BLM implements the market-based pricing mechanism recommended in this report, the retail price for helium may commensurably increase, which will have an even greater negative impact on those helium users.

These negative impacts could, however, be mitigated at least in part through a programmatic and policy change that would allow small users being supported by government contracts and grants to participate in a program—commonly referred to as the in-kind program[5]—operated by BLM for the sale of helium to

[5]The in-kind program is discussed in more detail in Chapter 5 in the section entitled "In-Kind Program of Crude Helium Distribution."

federal agencies and their contracting agents. Under that program, qualified buyers purchase their refined helium indirectly from BLM on a cost-plus basis.[6] Notably, participants in the program have priority access to helium in times of shortages.[7] The committee believes that such an expansion of the in-kind program would eliminate supply concerns and many of the price fluctuations that have negatively affected federally funded researchers during the past few years. Further, such an extension would be without significant cost to the programs supporting these researchers and, indeed, should lead to a more efficient use of the federal funds being used to purchase helium.

Recommendation. The crude helium in-kind program and its associated customer priorities should be extended by the Bureau of Land Management, in cooperation with the main federal agencies not currently participating in the in-kind program—for example, the National Science Foundation, the National Institutes of Health, and the extramural grant programs of the Department of Energy—to research being funded in whole or in part by government grants.

In addition to recommending that these users be allowed to participate in the in-kind program, the committee believes that the conservation and reuse of helium by these users should be promoted by the agencies funding this research. Although adopting such a policy may be costly in the short run, the committee judges that it would save money in the long run and would help to reduce many of the negative effects of the price and supply disruptions referred to in the preceding discussion.

Recommendation. Federal agencies such as the Department of Energy, the National Science Foundation, the National Aeronautics and Space Administration, and the Department of Defense, which support research using helium, should help researchers at U.S. universities and national laboratories acquire systems that recycle helium or reduce its consumption, including low-boil-off cryostats, modular liquefaction systems, and gaseous recovery systems.

The committee notes that because total U.S. research applications account for only 2 to 4 percent of all usage of refined helium in the United States, the negative

[6]As discussed more fully in the section of Chapter 5 entitled "In-Kind Program of Crude Helium Distribution" the price is negotiated between the supplier and user and includes BLM's cost of crude helium plus refining and transportation costs and profits for the refiner and distributor.
[7]50 U.S.C.A. Section 167d (a).

effects of supply and price disruptions for the U.S. research community not currently participating in the in-kind program could be addressed at relatively low cost. Moreover, in the judgment of this committee, the benefits for the nation that would accrue from minimizing these disruptions would be substantial.

General Recommendations for Meeting U.S. Helium Needs

In addition to the specific recommendations just discussed, the committee sets out more general recommendations for how to best meet the nation's current and future helium needs. These include recommendations for (1) collecting and making available the information needed to more effectively manage the Federal Helium Reserve and to formulate future helium policy and (2) initiating strategies to develop a more comprehensive long-term program for meeting the nation's helium needs.

Collection of Information

One of the difficulties encountered by this committee and the previous NRC committee that issued the 2000 Report was the lack of timely and sufficient information to evaluate the supply and demand sides of the helium market, especially non-U.S. supply and demand, and the operation of the Federal Helium Reserve. Such information is needed by those who formulate and carry out U.S. policies on helium in order to make good decisions.

Recommendation. The Bureau of Land Management (BLM) should acquire, store, and make available to any interested party the data to fill gaps in (1) the modern seismic and geophysical log data for characterization of the Bush Dome Reservoir; (2) information on the helium content of gas reservoirs throughout the world, including raw data, methodology, and economic assessment that would allow the classification of reserves contained in specific fields; and (3) trends in world demand. BLM or other agencies with the necessary expertise, such as the U.S. Geological Survey, should develop a forecast over the long term (10-15 years) of all U.S. demand for helium for scientific research and for space and military purposes.

Recommendation. Unless expressly prohibited from doing so, the Bureau of Land Management should publish its database on the helium concentrations in the more than 21,500 gas samples that have been measured throughout the world and provide its interpretations of gas sample analyses, especially those reflecting likely prospective fields for helium.

Long-Range Planning

Helium is critically important to many U.S. scientific, industrial, and national defense sectors. Further, the helium market is rapidly changing, as evidenced by the unforeseen developments on both the supply side and demand side of that market since the 2000 Report was released. Finally, because the Reserve is so large, steps undertaken in connection with it can have unintended consequences, the most pertinent being the effect of the pricing mechanism adopted by BLM pursuant to the 1996 Act on worldwide prices for helium. These considerations merit the development of a more permanent and sustained plan for managing this valuable resource.

In addition, the Federal Helium Reserve is a finite resource and so at some point in the future will be depleted. However, the helium needs of users in the in-kind program will continue. The BLM and the White House Office of Science and Technology Policy (OSTP) should develop a strategy to address these important future needs.

Recommendation. The Bureau of Land Management should promptly investigate the feasibility of extending the Helium Pipeline to other fields with deposits of commercially available helium as a way of prolonging the productive life of the Federal Helium Reserve and the refining facilities connected to it.

Recommendation. The Bureau of Land Management (BLM) should form a standing committee with representation from all sectors of the helium market, including scientific and technological users, to regularly assess whether national needs are being appropriately met, to assist BLM in improving its operation of the Federal Helium Reserve, and to respond to other recommendations in this report.

Recommendation. The Bureau of Land Management, in consultation with the Office of Science and Technology Policy and relevant congressional committees, should commission a study to determine the best method of delivering helium to the in-kind program, especially after the functional depletion of the Bush Dome Reservoir, recognizing that this will not happen until well after 2015.

Recommendation. The congressional committee or committees responsible for the federal helium program should reevaluate the policies behind the portions of the 1996 Act that call for the sale of substantially all federally owned helium on a straight-line basis. It or they should then decide whether

the national interest would be better served by adopting a different sell-down schedule and retaining a portion of the remaining helium as a strategic reserve, making this reserve available to critical users in times of sustained shortages or pursuant to other predetermined priority needs.

CONCLUSION

The committee notes that securing a stable and accessible helium supply in the future requires addressing several important issues that are beyond the scope of this study. For example, the legislative framework for the operation of the federal helium program is silent on the management of the Federal Helium Reserve after January 1, 2015, the mandated date for disposal of substantially all federally owned crude helium. What is to be done with the remaining federally owned crude helium? How will BLM operations beyond 2015 be financed? Should the Reserve, either as a federal or a private entity, as appropriate, continue to exist after the BLM debt to the U.S. Treasury has been retired? While the committee supports maintaining a strategic reserve, addressing these issues requires the involvement of Congress and the broader federal science policy establishment because the issues go well beyond the reserve management responsibilities of BLM.

1

Overview, Conclusions, and Recommendations

The U.S. Department of the Interior's Bureau of Land Management (BLM) is steward of the Federal Helium Reserve (see Box 1.1), the only significant depository of crude helium in the world. Helium is a critical component in many fields of scientific research, is needed in a number of important high-technology manufacturing processes, is indispensable to the U.S. space exploration program, and plays an important role in defense activities on the battle field and elsewhere. For many of these uses, there is no substitute for helium, so when shortages occur, operations must cease. Further, helium is a nonrenewable resource—it is found in only a few locations and many of the deposits in the United States are being depleted. Accordingly, the United States has an important interest in ensuring that critical users have an uninterrupted supply of helium. Indeed, this was the original reason for creating the Helium Reserve, and its proper stewardship is critical for ensuring that supply.

This report considers whether selling off the helium in the Helium Reserve in the manner prescribed by the 1996 Helium Privatization Act, discussed in detail below, has adversely affected U.S. users of helium for scientific, technical, biomedical, and national purposes. It examines the helium market and the helium industry supply chain and considers how the organizational and legislative framework impacts the ability of the Reserve to respond effectively to the dynamics of the helium market.

Chapter 1 surveys the committee's findings and its conclusions and recommendations. Subsequent chapters discuss the findings in more detail. They include assessments of the supply chain for helium (Chapter 2), the demand side of the

BOX 1.1
What Is the Federal Helium Reserve?

The Federal Helium Reserve, also referred to herein as the Helium Reserve or the Reserve, consists of

- The Bush Dome Reservoir, a naturally occurring underground structural dome near Amarillo, Texas, where federally owned (and some privately owned) crude helium is stored,
- An extensive helium pipeline system running through Kansas, Oklahoma, and Texas (the Helium Pipeline) that connects crude helium extraction plants with each other, with helium refining facilities, and with the Bush Dome Reservoir, and
- Various wells, pumps, and related equipment used to pressurize the Bush Dome Reservoir, to place into and withdraw crude helium from it, and to operate other parts of the Helium Reserve.

BLM, as operator of the Reserve, also has an interest in the partnership Cliffside Refiners LP, which owns a crude helium enrichment unit and related compression units (the "Enrichment Unit"). The Enrichment Unit, located at the Bush Dome Reservoir, is designed to produce crude helium of sufficient concentration and pressure for further refining. Pursuant to the partnership agreement, BLM is responsible for operating the Enrichment Unit. The four partners in Cliffside Refiners LP are companies that operated helium refining facilities connected to the Helium Pipeline when the partnership was founded. See Chapter 5 for a more detailed discussion of the Federal Helium Reserve.

helium market (Chapter 3), the current and expected future sources of helium (Chapter 4), and the operation of the Federal Helium Reserve itself (Chapter 5).

INTRODUCTION

In addressing its charge, the committee was struck by the fact that although the helium market is relatively small—the amount of helium consumed domestically each year is a tiny fraction of the market for produced gases[1]—the helium industry is quite complex. On the demand side, helium has many different applications, some more important than others from the perspective of national interest and some impacted more directly than others by how the Reserve is managed.

[1]The average annual amount of fuel-based gases (natural gases produced for use as fuel) consumed in the United States from 2004 to 2006 was approximately 20,000 billion cubic feet (Bcf) (Energy Information Administration, 2009). In contrast, helium's average annual domestic consumption for 2006-2009 has been approximately 2.5 Bcf, or slightly more than one one-hundredth of 1 percent of the fuel-based gas market (USGS, 2009).

The supply side of the helium market presents its own complexities. First of all, helium is a derived product (a term that will be defined shortly), which makes assessing the consequences of various options difficult. Helium is also a niche market with high barriers to entry, such that much of the supply chain is dominated by a few companies. This raises transparency and responsiveness issues when assessing the steps this committee might recommend and BLM might undertake. Finally, the existence of the Helium Reserve itself, which currently satisfies over one-half of the annual U.S. demand for helium and supplies approximately one-third of the annual global consumption, is a complicating factor. Any significant change in the amount of helium supplied from the Reserve could greatly impact its availability and pricing. All of these factors must be taken into account in assessing whether selling off the Helium Reserve in the manner prescribed by law has had any adverse effect on important users of helium in the United States.

This chapter begins with a discussion of why helium has become so important to such a disparate set of activities. It goes on to briefly describe the sources of helium and how it is extracted from natural gas, refined, and moved through the supply chain to the end users. Next, the chapter proceeds to the market issues surrounding helium and how they affect the committee's assessments and recommendations. The important role played by the Reserve in meeting both domestic and foreign needs is then discussed, including how BLM's operation of the Reserve affects the market. In response to the charge to the committee, included in this discussion is an assessment of the predictions of the 2000 Report (National Research Council, 2000) in light of developments in the helium market during the last decade. The chapter ends with recommendations that address some of the shortfalls in current actions and some final, concluding remarks.

DEMAND FOR HELIUM

Applications

The many uses for helium arise from its unique physical and chemical characteristics—specifically, its stable electronic configuration and low atomic mass. Among those unique characteristics are the temperatures at which helium undergoes phase transitions. Helium has the lowest melting and boiling points of any element: It liquefies at 4.2 Kelvin and 1 atmosphere and solidifies only at extremely high pressures (25 atmospheres) and low temperatures (0.95 Kelvin). These characteristics have led to many cryogenic applications for helium in science, industry, and government, and those uses make up the largest single category of applications by percentage of helium consumed.

TABLE 1.1 Helium Uses in the United States

Category	Representative Application	U.S. Share (%)
Cryogenics		28
	Magnetic resonance imagining	
	Fundamental science	
	Industrial cryogenic processing	
Pressurize/purge		26
	Space and defense rocket purging and pressurizing	
Welding		20
Controlled Atmospheres		13
	Optical fiber manufacturing	
	Semiconductor manufacturing	
Chromatography/ lifting gas/heat transfer		7
	Chromatography	
	Weather balloons	
	Military reconnaissance	
	Heat transfer in next-generation nuclear reactors	
	Party balloons	
Leak detection		4
Breathing mixtures	Commercial diving	2

SOURCE: USGS, 2007. These data are extrapolated from data in a USGS survey conducted by BLM personnel in 2003. Current shares are not known precisely but are expected to be approximately as shown.

As the second lightest element, gaseous helium is much lighter than air, causing it to be very buoyant. When combined with helium's chemical inertness—especially when compared with the highly flammable alternative, hydrogen—its buoyancy makes helium an ideal lifting gas. Uses that depend on helium's lifting capability include military reconnaissance, weather monitoring, and party balloons.

Other applications draw on other characteristics of helium—its relatively high thermal conductivity, low viscosity, and high ionization potential—either alone or in combination. These applications include welding, providing controlled atmospheres for manufacturing operations, and detecting leaks in equipment providing vacuum environments to science and industry. Table 1.1 summarizes the principal applications of helium and the share of use in the United States.[2] A more detailed discussion of helium's many uses is contained in Chapter 3.

[2]Because of the very limited data available on foreign consumption, the percentage breakdown of helium uses outside the United States is not available. However, with the exception of welding, where limited availability and historically higher helium prices have encouraged the substitution of argon and other gases for this use, foreign uses are similar to those in the United States.

Consumption

The balance between domestic and foreign consumption of helium has shifted significantly in the past 15 years. Until the mid-1990s, substantially all helium production took place in the United States. This factor, combined with high shipping costs and limited availabilities, meant that until recently, the amount of helium consumed abroad was fairly small. In 1995, for example, over 70 percent of worldwide helium consumption was in the United States (see Figures 1.1 and 1.2).

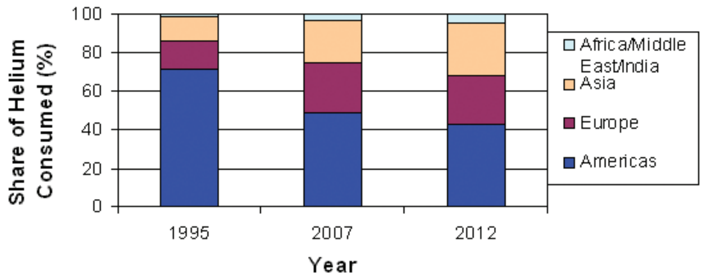

FIGURE 1.1 Helium demand, actual and forecasted, among regions of the world over time. In 1995, total volume sold was 3.750 billion cubic feet (Bcf); in 2007, total volume sold was 6.335 Bcf, and in 2012, it is expected to be 6.5 Bcf. SOURCE: Cryogas International.

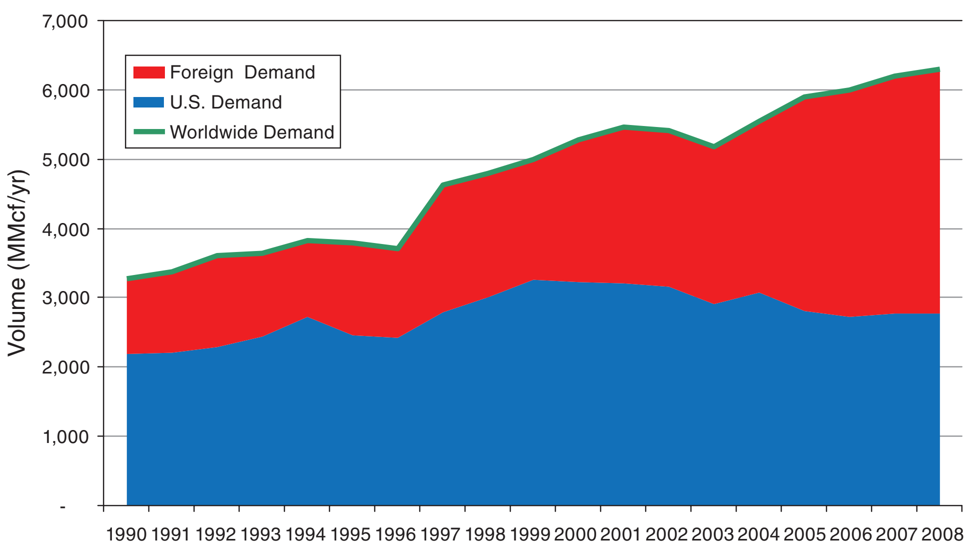

FIGURE 1.2. Consumption of refined helium in the United States (blue), in other countries (red), and worldwide (green line) for the years 1990 through 2008. SOURCE: Cryogas International.

Since that time, the demand for helium in the United States has remained fairly constant but has grown significantly elsewhere, reducing the U.S. share of total consumption. Foreign growth has been assisted by the opening of several helium-producing facilities outside the United States as well as by improved capabilities in the short-term storage and handling of refined helium. This period also saw a significant increase in industrial applications, principally in semiconductor and optical fiber fabrication facilities outside the United States, and the shifting of industrial facilities that use helium from the United States to foreign countries. By 2007, United States helium consumption had dropped to below 50 percent of worldwide demand. Despite a slight downturn in overall demand for helium associated with the global recession in 2008-2009, the committee believes, based on recent trends, that foreign demand should continue to increase relative to demand in the United States, such that U.S. relative consumption is expected to drop even further by 2012, to 43 percent.

SUPPLY OF HELIUM

Sources

Helium is the second-most-abundant element in the universe, but its diffusive properties mean that atmospheric helium leaks into space, rendering it relatively scarce on Earth.[3] At only 5.2 parts per million (ppm) in air, it is not economically feasible to extract helium from the atmosphere using current technology. Rather, the principal source of helium is natural gas fields. Helium nuclei (or alpha particles) are produced in the radioactive decay of heavy elements such as uranium and thorium, located in Earth's crust. While most of these helium atoms find their way to the surface and escape, a small fraction are trapped by the same impermeable rock strata that trap natural gas. Such natural gas usually consists primarily of methane and secondarily of ethane, propane, butane, and other hydrocarbons and various other contaminants, including H_2S, CO_2, and He.

Recovery of Helium

There are three different situations in which helium contained in natural gas may be economically recovered:

[3]In this report helium refers to the natural isotopic abundance of helium, essentially all helium-4. Helium-3, which has its own issues associated with its production and limited supply, is not a focus of the report.

- Helium may be extracted as a secondary product during the primary process of producing methane and natural gas liquids (NGLs) such as propane, ethane, butane, and benzene.
- For natural gas fields with sufficient concentrations of helium and other nonfuel gases such as sulfur and CO_2 to economically justify their extraction, the gas in those fields may be directly processed for the nonfuel constituents.
- Helium may be extracted during the production of liquefied natural gas (LNG), which consists primarily of liquefied methane.

For the first two recovery processes, current technology requires threshold concentrations of 0.3 percent helium before separation of the helium is commercially feasible. For the third process, the helium is extracted from the tail gases, the gases that remain after the methane has been liquefied. The helium concentration in those tail gases is much higher than in the original gas, allowing the economical extraction of helium even through the original natural gas might contain as little as 0.04 percent helium.

In the first two processes, the final product—refined helium—typically is produced in two steps. First, the natural gas goes through several stages in which water, methane, and the NGLs are removed, producing a gas containing 50-70 percent helium, commonly referred to as crude helium. For extraction facilities not connected to the Helium Pipeline, the crude helium then immediately undergoes further separation and processing, generating a refined helium end product of varying purity (from 99.99 to 99.9999 percent helium). Refining the tail gases in the last of the three extraction processes presented above is similar to the processing of crude helium just described.

Crude helium extraction facilities connected to the Helium Pipeline have two options: (1) immediately transporting the crude helium to an adjoining helium refining facility, or (2) compressing it for transport through the Helium Pipeline to another refining facility connected to the Helium Pipeline or for transfer to the Bush Dome Reservoir for storage. Once stored, it can later be retrieved and further processed to produce refined helium.

Helium Supply Chain

After being refined, helium is transported to end users through a fairly complicated supply chain. In the United States, the helium typically is liquefied and delivered by refiners either to their transfill stations situated throughout the United States or to distributors of industrial gases. This transportation is handled using expensive domestic tanker trucks or bulk-liquid shipping containers standardized according to the International Organization for Standardization (ISO), each of which holds approximately 1.0 to 1.4 million cubic feet (MMcf) of helium.[4] While some of the largest helium users contract directly with a refiner for their helium purchases and deliveries, most sales to end users are through the retail division of a refiner or a distributor. The refiners and distributors then repackage the helium, either in its liquid state into dewars—evacuated, multiwalled containers designed to hold liquid helium—of varying sizes or in its gaseous state into pressurized cylinders, tube-trailers, or other modules as needed by the end users.

MARKET ISSUES

Several facets of the helium market impact the committee's assessments and recommendations. The first is the nature of the helium sources. Helium is a derived product: Its availability principally depends on the production of other products such as methane and NGLs. This has several consequences. One is that the ability to respond to increased helium demand requires, at a minimum, additional sources of natural gas with at least threshold helium concentration. Just as important, reserves for derived products such as helium are not like primary product natural gas or oil reserves in the sense that the reserve remains in place until economic or other considerations justify recovery. Even for natural gas deposits with a relatively high percentage of helium, that helium is lost when the natural gas is extracted unless significant investments have been made in complementary helium extraction facilities.

The second significant aspect of the market is the concentrated nature of the supply chain, at least through the refining stage. Because the market for helium is highly specialized, with far fewer customers and dollars generated than by markets for natural gas and crude oil, and requires specialized and expensive equipment for producing and transporting the helium, essentially all crude helium is refined and made available to the rest of the supply chain by a very limited number of companies (see Figure 1.3). The United States has 10 refining facilities owned by 8 companies. Only 6 of those facilities, owned by 4 companies, are located on the Helium Pipeline, and only these 6 facilities can process the federally owned crude helium stored in the Bush Dome Reservoir. These facilities also have access to crude helium extracted from natural gas in deposits near the Helium Pipeline—largely in the Hugoton natural gas field spanning Texas, Oklahoma, and Kansas. The helium from those fields is produced as a by-product of methane and NGLs (the first of the three helium extraction processes described in the section on recovery).

[4]Various units are used to measure helium, and unless stated otherwise such measurements are assumed to be made at 70°F and 14.7 psia. This report uses multiples of cubic feet and cubic meters: Bcf = billion cubic feet; MMcf = million cubic feet; Mcf = thousand standard cubic feet. There are 35.3 cubic feet in 1 cubic meter.

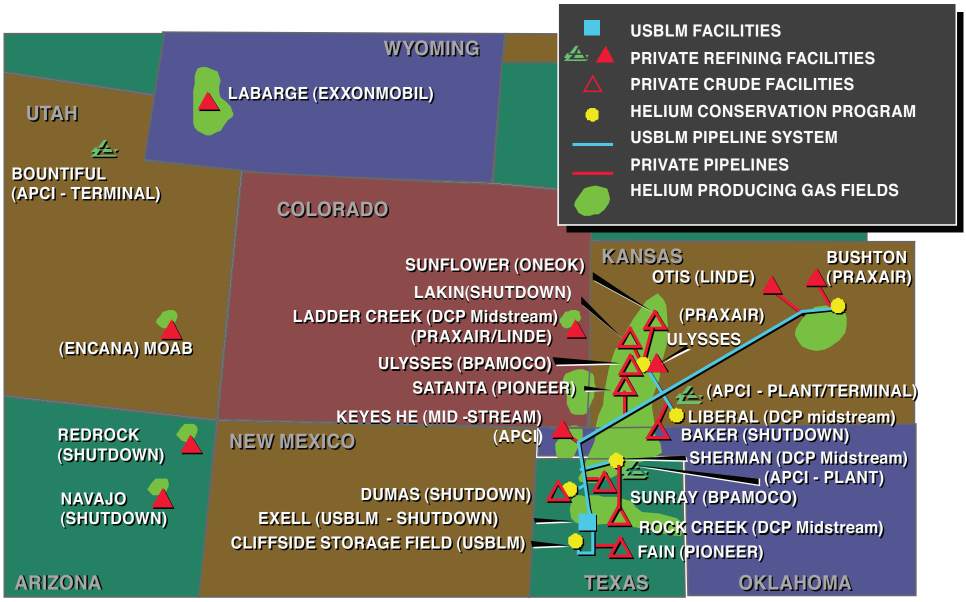

FIGURE 1.3 Map of the helium supply sources and major facilities in the United States. SOURCE: Air Products and Chemicals, Inc.

ExxonMobil owns a stand-alone crude helium extraction facility near Shute Creek, Wyoming, that has the largest helium refining capacity in the world. It processes natural gas in fields near the facility to recover non-fuel gases such as helium and CO_2. The remaining three helium refining units are small facilities in the western part of the United States that produce helium under one of the first two described extraction processes.

The concentrated nature of the segment of the helium market that purchases and refines crude helium has several effects. First, and most important, there is no actual "market" for crude helium, in the sense that potential purchasers and sellers engage in publicly ascertainable bids and sales of crude helium, with the price fluctuating depending upon the relative numbers and interests of those participating. Consequently, there is no market price for crude helium. Rather, other than the public sales of federally owned helium from the Bush Dome Reservoir, discussed in the following section, all sales of crude helium involve negotiations between a fairly small number of companies engaged in refining and a similarly small number of companies producing the crude helium, and the terms, including the prices at which crude helium is sold, are not typically made public. Second, given that refining the helium must take place at one of the facilities connected to the Helium Pipeline, the limited number of potential processors of federally owned crude helium place significant restrictions on alternatives to the current sale procedures being followed by BLM.

The final complicating facet of the helium supply chain is that because storing large amounts of helium is quite expensive, suppliers and end users generally do not stockpile it. Other than the Bush Dome Reservoir there are no significant long-term helium storage systems in the world.[5] The average amount of time that helium is in the supply chain, from the time it is separated from natural gas until it is delivered to the ultimate consumer, is between 45 and 60 days, so that any significant disruption in the supply of crude helium to refiners or the processing of that helium into refined helium is felt almost immediately by end users.

FEDERAL HELIUM RESERVE

The federal government has been extensively involved in the production, storage, and use of helium for almost as long as there have been commercially extractable sources of helium. This involvement began in the early decades of the 20th century, shortly after it was discovered that gas fields in the middle of the U.S. continent contained sufficient concentrations of helium to justify separating the helium from the natural gas. In the early years, helium principally was used for its lifting capability, as a safe alternative to highly flammable hydrogen. By the mid-1920s full-scale production facilities had been built and were being operated by the federal government to support its lighter-than-air aviation programs.

Although much of the infrastructure predates the cold war, the Federal Helium Reserve as a program, including establishment of the Bush Dome Reservoir as a crude helium depository, was established in 1960 as part of the country's cold war efforts. The Reserve was intended to provide a ready and uninterruptible supply of helium for the rapidly expanding needs of defense, the burgeoning space program, and scientific research. The federal government encouraged private companies to invest in helium extraction facilities and invested significant sums in purchasing helium. However, by 1973 it was apparent that the consumption of helium was significantly less than the amounts that could be purchased by the U.S. government. At that time over 35 Bcf had been placed on deposit in the Bush Dome Reservoir, many times the approximately 650 MMcf of helium being consumed annually at the time (Bureau of Mines, 1973). Consequently, the U.S. government quit accumulating any crude helium, and for the next 20 years, the net amounts

[5]The Russian Federation is reported to store helium in a salt dome near its Orenberg Plant. The amount of helium stored there and the length of time for which it is stored are not known.

of crude helium placed into storage in the Bush Dome Reservoir roughly equaled the amounts withdrawn.[6]

The 1996 Helium Privatization Act

In an effort to resolve outstanding issues associated with the Federal Helium Reserve, Congress enacted the Helium Privatization Act of 1996 (P.L. 104-273) (hereinafter the 1996 Act). The principal directive of the 1996 Act is that all but 600 MMcf of the helium on deposit in the Federal Helium Reserve should be sold by January 1, 2015, at prices sufficient to repay the federal government in full for its initial outlays for the helium, plus interest.

The 1996 Act also created what is referred to in the helium industry as the in-kind program (50 U.S.C.S. §167d(1)). Before the 1996 Act, federal agencies were required to make their major helium purchases directly from BLM's predecessor, the Bureau of Mines (BOM).[7] Because the 1996 Act required that BLM shut down its helium refineries, it established a program by which federal agencies and their contractors that use helium must meet their helium needs by buying refined helium from a private company that, in turn, is required to purchase a like amount of crude helium from BLM. The price for helium under this program is on a cost-plus basis, whereby the private company charges the federal agency or contractor the BLM cost of crude plus the company's costs of refining and transporting the helium, together with a profit. Importantly, purchasers of refined helium under the in-kind program are entitled to priority treatment in the event of helium shortages.[8] Current regulations restrict access to the in-kind program to federal agencies or contractors with federal agencies that use more than 200 Mcf of gaseous helium

[6]Part of the rationale behind the value of the Bush Dome Reservoir is that it can serve as a flywheel for the storage of crude helium that has been extracted but is not immediately in demand. The effectiveness of that usage is evaluated in more detail in Chapter 5, in the section "Efficiency and Conservation Benefits of the Flywheel." While the committee supports the idea of having the reservoir available to serve as a flywheel, it has not been able to obtain any data indicating it was ever used as such.

[7]Shortly before enactment of the 1996 Act, Congress passed legislation closing BOM. In that legislation, BOM's responsibilities with respect to the federal helium program were transferred to the BLM, which also operates under the Department of the Interior. Available at http://www.doi.gov/pfm/par/acct1995/ar1995bom.pdf.

[8]In addition to the mandatory sale provisions of 50 U.S.C. §167d(1), the subsequent subsection, 50 U.S.C. §167d(2), authorizes BLM, as agent for the Secretary of the Interior, to sell crude helium for Federal, medical, scientific, and commercial uses in such quantities and under such conditions as [the Secretary of the Interior] determines. According to BLM s representatives, no provisions have been made for the optional sale of helium under this portion of the 1996 Act.

or more than 7510 L of liquid helium per year.[9] Chapter 5 discusses the in-kind program in more detail.

NRC 2000 Report

The final section of the 1996 Act directed that the National Academy of Sciences be retained to review the 1996 Act and to assess its likely effects on the future price and supplies of refined helium. The report from that review, the 2000 Report (National Research Council, 2000),[10] concluded, among other things, that the 1996 Act would not have a substantial impact on helium users. The authoring committee found that the helium market was in an extended period of stability and that no drastic increases in the price of helium or shortages of supply had occurred since the mid-1980s. It also found that because the price established by the 1996 Act for the sale of federally owned crude helium was significantly higher than the then-current prices for privately owned crude helium, and because the helium refineries on the Helium Pipeline were under long-term contracts with the natural gas companies establishing the prices they would pay for privately owned crude helium, it was highly unlikely that the refining industry would buy gas from the Helium Reserve, other than as a last resort to meet unanticipated customer demand or to satisfy obligations under the in-kind program to supply the helium needs of federal agencies.

The committee that wrote the 2000 Report made several recommendations. Among those recommendations were the following. First, it recommended that BLM commission reviews of the helium industry if drastic increases or decreases in helium capacity or use occur, but in any event every 5 to 10 years. Second, it recommended that BLM improve its methods for tracking helium capacity and use, so that adequate information would be available to assess important shifts in the industry. Third, it recommended that BLM conduct a study to determine the adequacy of the Bush Dome Reservoir as the reserves were being drawn down and to evaluate whether the quantity of helium that was to remain in the Reserve would be able to meet future federal needs if private production were to drop temporarily. Finally, the committee recommended that the Department of the Interior develop a series of research and development projects to ensure a continued supply of helium.

[9]43 CFR Part 3195. At the committee's third meeting, BLM representatives confirmed that small-scale research programs are not permitted to participate in the in-kind program because they fall below the minimum usage requirements of the regulations and typically are not contractors with a federal agency. However, as this report was being finalized, BLM representatives indicated that they now believe such researchers are permitted to participate in the in-kind program. Clarification of this point in the language of the regulations would be beneficial in resolving this issue.

[10]This was not the first Academies report on national interests with respect to helium. These issues were also discussed in a 1978 report (National Academy of Sciences, 1978).

POST-2000 DEVELOPMENTS IN THE HELIUM MARKET

BLM implemented several of the recommendations of the 2000 Report. It engaged a Denver-based company that specializes in reservoir evaluations, NITEC LLC, to assess its operation of the Bush Dome Reservoir. Around the same time, BLM negotiated and entered into a partnership with the four companies then owning helium refining facilities on the Helium Pipeline. The partnership, Cliffside Refiners LP, had as its principal objective the design, purchase, and installation of equipment to enrich and compress the crude helium in the Bush Dome Reservoir so that the helium could meet specifications required by the refining facilities.

As noted in the 2000 Report, the prices charged for privately owned crude helium immediately following enactment of the 1996 Act were significantly below the prices to be charged by BLM. However, during the years following enactment of the 1996 Act, at which point the price at which BLM would be selling significant amounts of federally owned helium had been established, the prices between private parties for crude helium began to rise, either under individual contract provisions that allowed for periodic negotiations of price openers or under conditions where contract expirations required renegotiation of the contract terms. In establishing crude helium prices, the private sector, both entities connected to the Helium Pipeline and those not connected, used the BLM crude price as a benchmark, particularly during the helium shortages of 2006 to 2007. The prices at which privately owned crude helium sold have increased accordingly such that at the time of this report they were, on average, at least equal to the BLM crude price and as much as 10 percent above that level. Many if not all of the contract adjustments also include escalation terms that maintain the premium over BLM set in the adjusted price terms of the renegotiated crude contracts (see Figure 1.4).[11]

As would be expected with such increases in crude helium prices, the price reported by BLM for standard retail (or Grade A) helium has also increased, more than doubling from 2002 through 2008 (see Figure 1.5).[12]

In 2008, the global economy underwent a significant slowdown. One consequence was that the demand for helium, principally in the industrial markets, dropped significantly. The best estimate available to members of the committee is

[11]As mentioned earlier in this section and discussed in more detail in Chapter 5, crude helium prices are not publicly available. This assessment of the relative price levels of privately and BLM-sold helium is based upon the knowledge of members of the committee.

[12]As part of its collection and reporting of data on the helium market, BLM annually reports the price of Grade A helium. According to information provided by BLM after the prepublication version of this report was released and as this report was being finalized, these reported prices are estimates, rather than a representative sampling. Further, retail prices for helium vary widely, given the range of costs associated with delivering helium to particular end users. However, the retail helium price increases reported by BLM are consistent with representative price increases obtained by committee members by sampling of scientific users of helium.

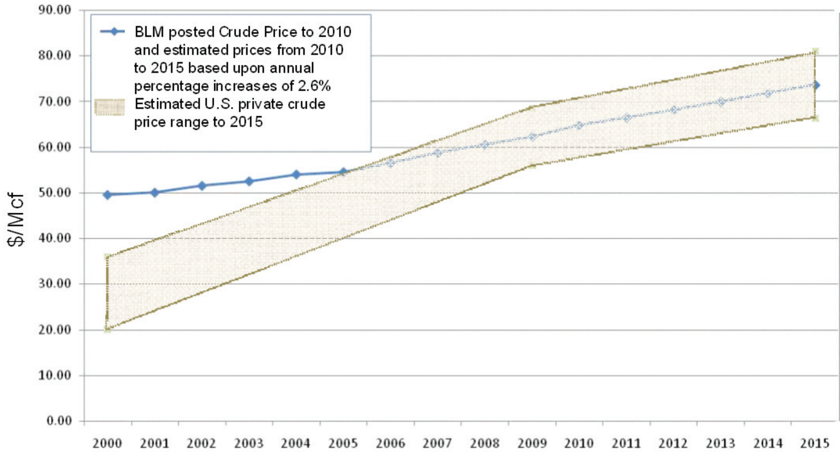

FIGURE 1.4 Actual and projected BLM crude helium prices (blue line), with annual percentage increases from 2010 to 2015 based on an estimated Consumer Price Index shift of 2.6 percent per year. The BLM posted crude price does not include additional pipeline use and service fees that average 5 percent of the posted price. Overall trend in selling prices for privately owned crude helium (shaded areas). See text for discussion.

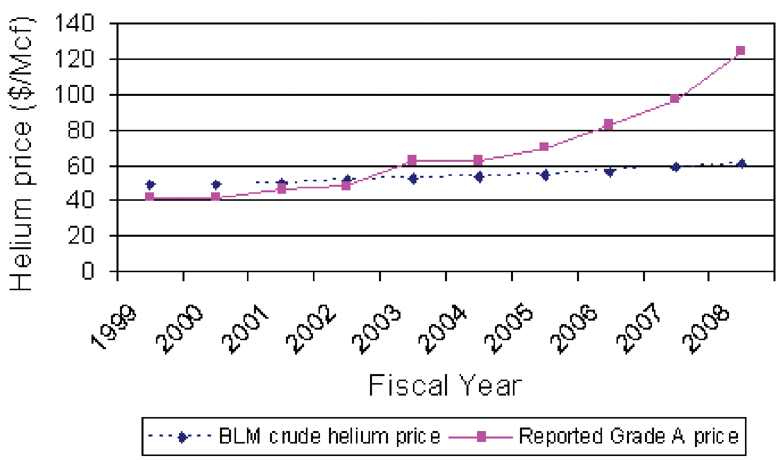

FIGURE 1.5 BLM crude and reported private Grade A, or standard retail, helium prices. SOURCE: USGS, 2006-2009.

that, at the time this report was written, demand for refined helium had dropped approximately 10 percent from the peak demand in 2007. However, prices for refined helium have remained substantially at the levels reached in 2007. In the judgment of the committee, the (eventual) recovery of the global economy from the 2008-2009 economic downturn is likely to result in continued growth in foreign demand for refined helium, as well as more growth of foreign supplies of crude helium.

REVIEW OF THE 2000 REPORT'S CONCLUSIONS

One of the charges to this committee is to determine the reasons for differences between the projected expectations of the 2000 Report and the actual outcomes. That charge is addressed in this section. The 2000 Report concluded as follows:

> The price of helium will probably remain stable through at least 2010. The price established by the Helium Privatization Act for sales from the Federal Helium Reserve is approximately 25 percent above the current commercial price for crude helium. For this reason and because all helium refiners on the BLM pipeline have long-term take-or-pay contracts with producers of crude helium, it is highly unlikely that the refining industry will buy and use gas from the Federal Helium Reserve rather than from private stockpiles of cheaper commercial suppliers. (p. 2)

The price of both crude and refined helium did not, however, remain stable through 2010 but rose steadily in the years following the issuance of the 2000 Report, as shown in Figures 1.4 and 1.5. By 2008, private industry crude prices became approximately the same as prices established by the BLM for the crude helium in the Bush Dome Reservoir. This has led to significantly greater withdrawals by refiners on the Helium Pipeline than the 2000 Report anticipated (see Figure 1.6).

The 2000 Report made no attempt to project future demand for refined or crude helium, presumably in part because of the poor quality of data on helium uses collected by the federal government. It also did not discuss foreign demand for helium in any detail, which may have further undermined the accuracy of its predictions of stable demand. As mentioned in the preceding section, one of the main changes in the helium market since 2000 has been a surge in foreign demand for helium, combined with a decline in U.S. demand (see Figures 1.1 and 1.2).

Much of this shift in the relative growth of domestic and foreign demand appears to be linked to the slow growth or reductions in helium consumption in U.S.-based semiconductor and fiberoptic manufacturing. Both of these manufacturing-related uses of helium grew significantly since 2000 in Asia, reflecting the expansion of production of fiberoptic cable and semiconductors within the region. Asian demand is projected to grow faster than U.S. or European demand (see Figure 1.1).

Commerce Department data indicate that U.S. domestic consumption of

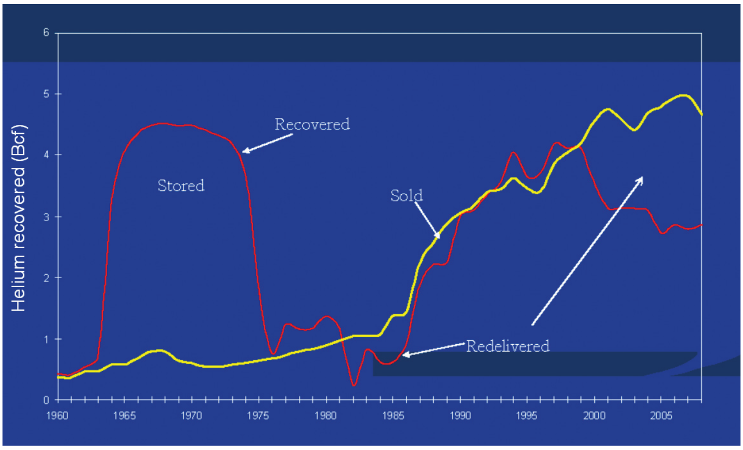

FIGURE 1.6 Crude helium recovered and removed from storage in the Bush Dome Reservoir, 1960-2008. A positive difference between the amount of helium recovered and sold in a given year constitutes an increase (by the amount of the difference) in the amount of helium stored in the Bush Dome Reservoir; a net negative difference constitutes a decrease (by the amount of the difference) in the amount of stored helium. SOURCE: U.S. Department of the Interior's Bureau of Land Management.

helium declined during 2000-2007 at an average annual rate of 2.7 percent.[13] Some of this decline reflects improved helium conservation and recycling. At the same time, U.S. exports grew at an average annual rate of 7.9 percent. Average annual growth in U.S. helium exports to Pacific Rim countries from 2000 to 2007 (6.8 percent) exceeded the growth of exports to Europe (5.1 percent).

These shifts in the domestic and foreign markets result in a growing share of U.S. domestic helium being exported. The United States remains the largest single source of crude helium in the world. But the depletion of the Hugoton field, which is the principal source of crude helium for refining facilities connected to the Helium Pipeline, and the relative shifts in the prices of crude helium such that the helium sold by the BLM now costs as much as privately owned helium, mean that a growing share of U.S. "production" of crude helium has consisted of withdrawals of crude from the Bush Dome Reservoir (see Figure 1.7).

The 2000 Report's discussion of crude helium supply focused largely on supply sources within the United States. The report argued that crude helium production from the Hugoton field would decline and production from the ExxonMobil facility in Wyoming would increase, a forecast that has proven largely accurate. The 2000 Report also mentioned the potential exploitation of crude helium associated with natural gas production in the Wyoming Riley Ridge field, and more recent forecasts

[13]Summarized in Garvy, 2008.

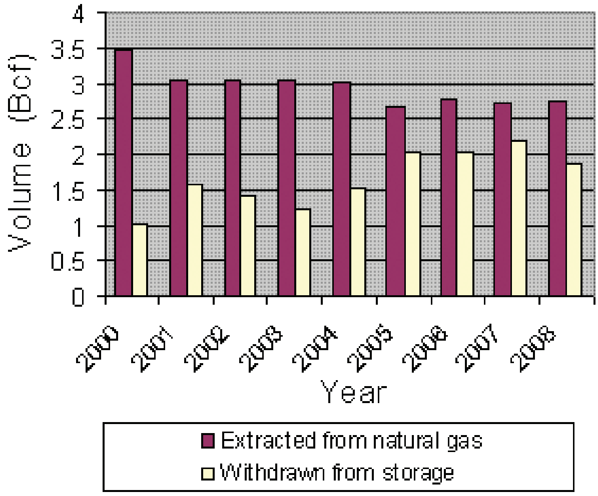

FIGURE 1.7 Crude helium production in the United States, 2000-2008, comprising helium extracted from natural gas and helium withdrawn from storage in the Bush Dome Reservoir. SOURCE: USGS, 2005a, 2009.

suggest that this source of crude helium will become significant after 2009. The 2000 Report devoted very little attention to foreign sources of crude helium beyond a brief mention of the potential production of crude helium associated with the production of LNG in Algeria.

Although foreign production of crude helium has expanded considerably beyond the levels projected in the 2000 Report, 2006 and 2007 were plagued by significant interruptions in both domestic and foreign supplies. During 2006, the unplanned shutdowns of U.S. refining facilities not linked to the Helium Pipeline, as well as a planned shutdown of the Enrichment Unit, contributed to global helium shortages and higher prices. But another important factor in the price and supply shocks of that 2-year period was the slow startup of helium production associated with new LNG production plants in Algeria and Qatar. Helium production at both locations was hampered by technical difficulties, limiting supply. Unexpected shutdowns of the helium processing plant in Russia also exacerbated supply shortages.

Conclusion. Developments in the supply and price for crude and refined helium did not follow the predictions of the 2000 Report.

It appears that some of its failure to correctly predict post-2000 developments reflected the focus of the 2000 Report on U.S. domestic supply and demand. In fact, however, the market for helium is now a global one, and the biggest demand-side shocks to this market reflected developments in foreign markets. Any future assessments of helium supply and demand must have access to better data on both U.S.

and foreign demand and supply of crude and refined helium. Moreover, the growth of foreign supply sources and the gradual decline of crude helium production in the United States from natural-gas extraction mean that foreign sources of crude helium will play a more important role in the future global market, and the performance of those supplies will affect helium price and availability for all users.

The inaccurate predictions in the 2000 Report of helium prices and supply also reflect fundamental uncertainties about both the demand and supply sides of the global market for helium, as well as the lack of publicly available data needed to project future supply and demand. Like the committee that wrote the 2000 report, this committee lacks data on characteristics and price-responsiveness of demand for helium on the part of the diverse population of industrial and scientific users, information needed to develop accurate projections of and responses to future prices. Consequently, the committee is able to provide only crude estimates of future growth in sources of supply. These uncertainties on both the demand and supply sides of the market for helium highlight an important design principle for future policy toward any federal helium program: Policies for management of this national resource must be able to accommodate shocks to the demand for and supply of crude helium.

CONCLUSIONS AND RECOMMENDATIONS FOR THE FEDERAL HELIUM PROGRAM

Having examined the global helium market, assessed the current and projected U.S. marketplace for refined helium, and assessed the role that organizational and financial factors play in meeting the goals of the federal helium program, the committee has reached some conclusions on the current situation and identified some recommendations that it believes will enable the program to respond more effectively to the helium market while also meeting national needs for this valuable national asset. More detailed discussions of the findings and rationales behind these recommendations can be found in the remaining chapters of the report.

New Policy for the Sale of Federal Helium

Both the language of the 1996 Act and its implementation by BLM pose obstacles to the optimal management of the Helium Reserve and its ability to serve U.S. national interests and the interests of U.S. taxpayers, who provided most of the resources for the construction of the Reserve and its associated infrastructure. The 1996 Act established a minimum selling price for the federally owned crude helium in the Bush Dome Reservoir. That price was arrived at by dividing the helium program's total debt by the amount of crude helium slated for sale from 2003 to 2015. While the price is specified as the minimum price and not necessarily the actual selling price, BLM has elected to sell the contents of the Bush Dome Reservoir at the minimum price, adjusting it each year by the change in the Consumer Price Index.

As was noted earlier, the BLM price initially was well above the market price for privately owned crude helium. Various factors, including significant shifts in supply and demand, caused the price of privately owned crude helium to increase steadily, reaching rough parity with the BLM price in 2007. Since that time, the price of privately owned crude helium has tracked the BLM price—in essence, BLM now is effectively setting the price for crude helium. As a result, the companies with refining facilities connected to the Bush Dome Reservoir now have access to a ready supply of crude helium at about the same price paid by other refiners not connected to the Bush Dome Reservoir. General economic considerations suggest that this effective setting of the price of crude helium by BLM's pricing policies may retard the efforts of these and other helium refiners to aggressively pursue alternative crude helium sources, thereby negatively impacting the evolution of the helium market.

In the committee's judgment, nothing in the 1996 Act prohibits BLM from moving toward a market-oriented pricing policy for sales of the crude helium in the Bush Dome Reservoir, as long as sales of the federally owned crude helium are priced at or above the legislated minimum. Moreover, selling the crude helium at market prices that exceed the current BLM price could enable more rapid retirement of the BLM facilities' debt to the U.S. Treasury, a central goal of the 1996 Act, and leave more than the required 600 MMcf of crude helium on reserve in the Bush Dome Reservoir after retirement of that debt, which the committee anticipates should occur before 2015.

Several unusual characteristics of the Helium Pipeline and refinery infrastructure, however, may complicate the development of a market pricing policy for federally owned helium reserves that is both transparent and more responsive to changes in demand conditions. Any purchaser of crude helium from the Reservoir must refine the crude helium into a gas or liquid product suitable for storage, transport, and sale. Moreover, economic considerations dictate that the processing of the crude helium must take place at a refinery on the Helium Pipeline.

The six refineries on the pipeline are owned by four firms, all of which are sellers of refined helium products in global markets and three of which are shareholders in Cliffside Refiners LP.[14] A market-based sales process for disposing of

[14]After the partnership was formed, the fourth shareholder, El Paso Energy, sold its helium refining facilities on the Helium Pipeline to another company, Keyes Helium LLC, a subsidiary of Midstream Energy, but retained its ownership interest in the partnership. Keyes is not an owner of the partnership.

the federally owned crude helium (e.g., through open auctions) almost certainly will require selling crude helium to competitors of these four firms, and any such purchaser might find it difficult to gain access to refining capacity. Market-based pricing for federally owned crude helium may not be feasible unless a policy is implemented that mandates timely access by any purchaser of crude helium to a Helium Pipeline-linked refinery.

Conclusion. The pricing mechanism used by BLM reflects the costs of the crude helium (as determined by the 1996 Act), not the value of the helium. The best data available to the committee indicate that since approximately 2007, the BLM price for crude helium has become the average price at which privately owned crude helium is being sold between private parties, and BLM, rather than market forces, is in effect, setting the price for crude helium. While recognizing the idiosyncratic nature of the helium market, the committee believes that if this situation persists, it could have several negative consequences. It could, for example,

- **Lead to inaccurate market signals, bringing about increased consumption and accelerating the depletion of the Federal Helium Reserve.**
- **Retard efforts to develop alternative sources of helium.**
- **Result in a net transfer of taxpayer assets to private companies.**
- **Cause the sales of federally owned crude helium to subsidize exports of helium.**

Conclusion. The expansion of market-based pricing of Bush Dome crude helium is hampered by the limited number of potential bidders—currently just four—whose refining facilities are connected through the federally owned Helium Pipeline to the Bush Dome Reservoir.

Recommendation 1. The Bureau of Land Management (BLM) should adopt policies that open its crude helium sales to a broader array of buyers and make the process for establishing the selling price of crude helium from the Federal Helium Reserve more transparent. Such policies are likely to require that BLM negotiate with the companies owning helium refining facilities connected to the Helium Pipeline the conditions under which unused refining capacity at those facilities will be made available to all buyers of federally owned crude helium, thereby allowing them to process the crude helium they purchase into refined helium for commercial sale.

Providing Helium for Small-Scale Science Research Communities

In addressing the principal component of its charge—namely, that it assess whether the operation of the Federal Helium Reserve in the manner prescribed by the 1996 Act has had any adverse effect on critical users in the United States—the committee notes that while rising prices and shortages have negatively impacted all users, their ability to respond varies significantly from group to group. For many of the industrial, biomedical, and larger national-security-related users, the rising costs are important but do not threaten the short-term viability of their operations. The principal exceptions to this statement are the small-scale scientific laboratories at U.S. universities and national laboratories. The committee has developed recommendations designed to address the concerns of this group of users, but the rationale for these recommendations requires some additional discussion.

The small academic laboratories typically are supported by grants from the National Science Foundation (NSF), the U.S. Department of Energy (DOE), the Defense Advanced Research Projects Agency (DARPA), and other government agencies. The grants used to support these small, helium-using laboratories usually range between $100,000 and $200,000 annually, with most in the lower end of that range. The research typically is carried out by the principal investigator (normally a faculty member at a research university), one or two graduate students, and—possibly—one or two postdoctoral fellows. Small-scale research projects at national laboratories that use helium receive slightly more funding—$250,000 to $1,500,000—that typically is awarded through the internal budgeting processes of these laboratories but is ultimately provided by the principal funding agencies mentioned above. The research is carried out much like university-based research but with technical staff—typically three or four full-time staff members rather than students—as the main workforce.

The annual consumption of liquid helium in the typical low-temperature physics research program is between 5,000 and 10,000 liters of liquid (1 liter of liquid expands to approximately 27 standard cubic feet of gas). Most of the research facilities at academic institutions are not included in the in-kind program but rather purchase their helium from local distributors. Research programs at national laboratories typically receive their liquid helium by participating in the collective purchasing procedure of the particular national laboratory with which they are affiliated. Many of these purchases take place through the in-kind program. The cost to an individual research project is the carry-through cost associated with purchasing and delivering the amount of helium consumed by that project.

Even before 2006, when liquid helium was priced at $3 to $5 per liter, liquid helium costs accounted for a substantial fraction of the grants. Since 2006, the cost of liquid helium has more than doubled and at the time of this report is between

$7 and $10 per liter. Thus, including indirect costs such as overhead charges, the annual cost of liquid helium for one of these programs is between $35,000 and $100,000, or as much as one-half of the entire operating budget of a university-based laboratory. While such increases make up a smaller percentage of the budgets for national laboratory projects, the $25,000 to $50,000 increases in annual helium costs create significant budget constraints for those projects as well. This can leave investigators in the undesirable situation of having to choose between delaying the purchase of needed equipment or forgoing research because of the inability to pay—in the case of university-based researchers—the stipends of graduate students or the salaries of postdoctoral researchers or—in the case of national laboratory-based researchers—the salaries of technical staff.[15]

Committee members conducted an informal poll of approximately 40 research programs at universities and national laboratories that use helium and learned of interrupted supplies of liquid helium for almost half of these programs, with some of the interruptions lasting for weeks at a time during the late summer and fall in 2006 and 2007. While these results are anecdotal, they clearly indicate that general shortages directly impact this community of users. Further, such shortages have significant adverse affects on users for small-scale scientific purposes. Because liquid helium continuously evaporates, these researchers must take small (100-200 liters) deliveries of liquid helium weekly. Shortages such as those experienced in 2006 and 2007 forced many researchers to abruptly halt their ongoing experiments, with adverse impacts. For these experiments to resume, the investigators must slowly return to operating temperatures, recalibrate their instruments, conduct background studies, and take other steps that often require weeks of extra work before they are able to resume their studies.

A small fraction of these researchers are in a less stressful situation, as their universities have campus-wide helium gas recovery and liquefaction systems to recycle the helium gas boiled off from cryostats. Access to such a system effectively cushions this group from short-term market interruptions in liquid helium supplies. Since the recovery rate of these systems typically is around 89 percent, the savings in the cost of purchasing helium can be substantial. However, the precise savings depend on the total consumption of the university and how the university accounts for the salary of the technician(s) that run(s) the liquefaction plant and for other infrastructure costs.

In summary, a small-scale laboratory or a typical project at a national labora-

[15]The committee's assessment is shared by at least one commercial analyst of the helium market: "Rising helium prices should lead to demand destruction at non-industrial helium consumers. Small science labs with less capital for helium conservation projects and small party businesses that use helium for balloon inflation are likely to be most vulnerable, whereas larger industrial manufacturers can install equipment to capture and recycle helium." Jefferies, 2008, at p.13.

tory on a fixed budget that faces increased helium costs and volatile supplies suffers major consequences—fewer funds are available to educate and train its students and postdoctoral researchers, and its research efforts are likely to be interrupted. These issues have serious long-term implications, hampering the training of future scientists and retarding the development of technologies that draw on research advances in these laboratories.

Conclusion. The majority of helium users at U.S. universities and national laboratories are funded by the federal government through grants. Many of the users, especially at universities, are not covered by the in-kind helium program, and some of them have had difficulty obtaining the helium they need during times of shortages, compromising fundamental research.

Conclusion. Because of their limited budgets, many helium users at universities and national laboratories have been adversely affected by rising retail prices for helium. If BLM implements a market-based pricing mechanism, as recommended in this report, it is anticipated the retail price for helium will increase commensurately, which will have an even greater negative impact on those helium users. These impacts could be ameliorated at least in part, however, through a programmatic and policy change that would allow small users being supported by government contracts and grants to participate in BLM's in-kind program.

Recommendation 2. The crude helium in-kind program and its associated customer priorities should be extended by the Bureau of Land Management, in cooperation with the main federal agencies not currently participating in the in-kind program—for example, the National Science Foundation, the National Institutes of Health, and the extramural grant programs of the Department of Energy—to research being funded in whole or in part by government grants.

In the committee's judgment, extending participation in the in-kind program could eliminate or reduce the severity of the supply and price fluctuations encountered by many users of refined helium for small academic research since 2006. Because the price of in-kind refined helium is based on the price charged by BLM for crude helium, plus costs, these small users should face significantly smaller price fluctuations than over the past few years. Furthermore, priority access to helium in times of shortages afforded to participants in the in-kind program should remove many of the supply issues encountered from time to time. 50 U.S.C.

Section 167d(2)[16] appears to provide legislative authority for such an extension of the in-kind program.

In addition to recommending that these users be allowed to participate in the in-kind program, the committee believes that longer-range planning would help to reduce the amount of helium needed for these research programs. For most experimental setups, equipment such as low-loss dewars and stand-alone reliquefiers, which condense gaseous helium boiled off from liquid helium, could significantly reduce the amount of helium consumed but their costs would exceed the budgets of most of these research programs. Because the funding agencies have a vested interest in reducing the vulnerability of small-scale users to volatility in the helium market, the committee believes that policies should be developed that will help to pay for the installation and maintenance of such equipment. While costly in the short run, recycling and recovery systems will eventually save enough money to pay back the initial costs and provide future savings, in addition to conserving helium for future uses. The committee also notes that because helium usage by this group accounts for only 2 to 4 percent of overall demand, the program would not significantly impact overall helium demand. Appendix D provides a more detailed discussion of the options available for such systems.

Chapter 3 discusses, in the context of all the different helium uses, efforts that have been taken or might take place in the future to conserve helium with respect to those uses, including discussions of possible substitutes, where applicable. The committee feels that market effects associated with significantly rising helium prices should generate appropriate conservation responses and that a more general recommendation to support conservation efforts for other parts of the helium market is not called for.

Recommendation 3. Federal agencies such as the Department of Energy, the National Science Foundation, the National Aeronautics and Space Administration, and the Department of Defense, which support research using helium, should help researchers at U.S. universities and national laboratories acquire systems that recycle helium or reduce its consumption, including low-boil-off cryostats, modular liquefaction systems, and gaseous recovery systems.

[16]"The Secretary is authorized to sell crude helium for Federal, medical, scientific, and commercial uses in such quantities and under such terms and conditions as he determines. Except as may be required by reason of subsection (a) of this section, sales of crude helium under this section shall be in amounts as the Secretary determines, in consultation with the helium industry, necessary to carry out this subsection with minimum market disruption." 50 U.S.C. §167d (b).

Management of the Federal Helium Reserve

For the next 10 to 15 years, the Federal Helium Reserve will provide a significant portion of the helium used domestically, and the committee believes the Reserve must be managed so that it repays U.S. taxpayers their investment in the Reserve and maintains the future availability of the helium for participants in the in-kind program and other critical users of helium in the United States. The debt associated with the Reserve should be retired prior to 2015 by selling helium and methane in the Bush Dome Reservoir.[17] If BLM implements a market-based pricing mechanism, as discussed in Recommendation 1, it would accelerate retirement of the debt, allowing BLM to invest in well repairs, update infrastructure, and undertake other critical steps to properly manage the Reserve to meet national needs.

One of the principal concerns of the committee—and also a concern of the committee issuing the 2000 Report—is that the 1996 Act's stipulation that the contents of the Bush Dome Reservoir be sold on a straight-line basis undercuts efficient extraction of the crude helium in the reservoir. Appendix F discusses some general considerations for developing a production strategy for reservoirs such as the Bush Dome Reservoir. The 2000 Report noted that unsold inventories of crude helium could build up and conflict with the straight-line language of the act if this language is interpreted as mandating that equal quantities of crude helium be sold each year. At present, capacity constraints associated with the extraction facilities for the reservoir mean that the system can sell no more than 2.1 Bcf per year.

A related concern is that while BLM has engaged a private firm to assess and advise on developing a management program for the Bush Dome Reservoir, the Reservoir's future performance remains uncertain. Chapter 5 discusses many of these issues in detail and suggests that some of these uncertainties could be reduced by acquiring and analyzing seismic data, drilling and logging additional wells, and developing a reservoir model that includes the additional data and examines the application of modern production technology, such as horizontal wells in strategic locations. Even so, uncertainty cannot be eliminated and, given the relatively advanced age of this field and reservoir, the expenses of finding the "best" forecast might not be justifiable. However, because the future performance of the Bush Dome Reservoir is so uncertain, particularly on the downside, it would be useful for BLM to consider how to deal with reservoir performance that falls well short of the base case predictions.

[17]When the 1996 Act was enacted, the value of the methane in the Bush Dome Reservoir was ignored for the purpose of establishing the schedule and pricing for retirement of the debt associated with the federally owned helium. In the intervening years, significant amounts of methane from the Bush Dome Reservoir have also been sold and the proceeds used to reduce the helium-related debt. Consequently, that debt should be retired well before the sale of all of the helium contemplated in the 1996 Act.

Conclusion. In the judgment of the committee, the extraction of crude helium from the Bush Dome Reservoir on the straight-line basis mandated by the 1996 Act, even if feasible in the later years of the reservoir's productive life, would be economically inefficient, might preclude access to significant amounts of helium in the Bush Dome Reservoir, and is not likely to meet the needs or interests of U.S. helium users and U.S. taxpayers.

Recommendation 4. The Bureau of Land Management should develop and implement a long-term plan that incorporates appropriate technology and operating practices for delivering crude helium from the Reserve in the most cost-effective manner. More detailed recommendations on management of different aspects of the Federal Helium Reserve are set forth in Chapter 5.

Collection of Information

One of the difficulties encountered by this committee and the NRC committee that wrote the 2000 Report was the lack of timely and sufficient information to evaluate both the supply and demand sides of the helium market and the operation of the Federal Helium Reserve. Such information is needed so that those who formulate and carry out U.S. policies on helium will have the information they need to make good decisions.

Conclusion. Efficient long-term management of the federal helium program requires that BLM have adequate information about the Bush Dome Reservoir and about current and potential sources of and demand for helium worldwide. Publicly available data for many aspects of the helium market are either incomplete or nonexistent, greatly hampering management efforts. Equally important, long-term management of the program requires that BLM have the capability to assess and respond to such data.

Recommendation 5. The Bureau of Land Management (BLM) should acquire, store, and make available to any interested party the data to fill gaps in (1) the modern seismic and geophysical log data for characterization of the Bush Dome Reservoir, (2) information on the helium content of gas reservoirs throughout the world, including raw data, methodology, and economic assessment that would allow the classification of reserves contained in specific fields, and (3) trends in world demand. BLM or other agencies with the necessary expertise, such as the U.S. Geological Survey, should develop a forecast over the long term (10-15 years) of all U.S. demand for helium for scientific research and for space and military purposes.

Recommendation 6. Unless expressly prohibited from doing so, the Bureau of Land Management should publish its database on the helium concentrations in the more than 21,500 gas samples that have been measured throughout the world and provide its interpretations of gas sample analyses, especially those reflecting likely prospective fields for helium.[18]

Longer-Term Needs

In addition to the short- and medium-term needs discussed in Recommendations 1-6, steps should be taken to proactively respond to longer-term needs of the principal users of helium in the United States. As discussed earlier, at current drawdown rates the amount of helium in the Bush Dome Reservoir will last, at most, for 10 to 15 more years. At that point, domestic sources of helium will not satisfy the demand of helium users in the United States; instead, domestic demand will need to be met, in part, by relying upon recently developed sources in locations such as the Middle East and Russia. While the demand of some of those users might not be deemed important or necessary, that of other users—such as government agencies, including the armed forces and NASA, scientific researchers, and certain industrial sectors—is critical to the goals and national interests of the United States. Steps should be taken to ensure adequate and uninterrupted supplies of helium for their continued use.

Conclusion. Extending the Helium Pipeline into areas known to have helium, such as parts of New Mexico and Arizona, will give potential producers of helium in those areas access to the storage capacity of the Bush Dome Reservoir and the refining capabilities of those facilities connected to the Helium Pipeline. Such an extension could encourage the development of more U.S. helium resources.

Recommendation 7. The Bureau of Land Management should promptly investigate the feasibility of extending the Helium Pipeline to other fields with deposits of commercially available helium as a way of prolonging the productive life of the Federal Helium Reserve and the refining facilities connected to it.

Conclusion. Given the reliance of global demand on the continued availability of helium from the Federal Helium Reserve for the next 2 to 3 years, there is little opportunity to significantly reduce the amount of federally owned

[18]A portion of the material recommended to be published is available through the National Technology Information Service (available under NTIS Order Number: PB2009-500006 at the time this report was written).

helium sold in the short term without interrupting the market. However, as foreign supplies of helium are expected to increase in 2009, the United States has an opportunity to evaluate whether the current policy to monetize federally owned helium remains appropriate, given recent changes in the market for helium. One alternative would be to leave sufficient helium in the Bush Dome Reservoir to provide for a multiyear U.S. reserve in the event of future market disruptions.

Conclusion. Helium is a nonrenewable resource and is valuable for a number of critical activities in science, industry, and defense in the United States. Significant changes have taken place in the helium market since enactment of the Helium Privatization Act of 1996 (P.L. 104-273)).

Recommendation 8. The congressional committee or committees responsible for the federal helium program should reevaluate the policies behind the portions of the 1996 Act that call for the sale of substantially all federally owned helium on a straight-line basis. It or they should then decide whether the national interest would be better served by adopting a different sell-down schedule and retaining a portion of the remaining helium as a strategic reserve, making this reserve available to critical users in times of sustained shortages or pursuant to other predetermined priority needs.

Further, as demonstrated by the unpredicted but significant increases in foreign demand for helium since issuance of the 2000 Report, the market for helium can be highly variable. Industrial and scientific uses that are not currently foreseen might easily arise and place critical helium users in the same tight market situation, with rapidly rising prices and periodic supply shortages as were experienced in 2006 and 2007. Conversely, one or more sources of natural gas, such as shale gas, might become an additional source of helium that could somewhat relieve tight market conditions if the helium capacity associated with it is recognized and encouraged. Steps should be begun now to develop a strategy to address these important future possibilities.

Conclusion. The variability of the helium market and its importance to critical components of U.S. scientific, industrial, and national defense sectors merits the development of a more permanent and sustained method for managing this valuable resource.

Recommendation 9. The Bureau of Land Management (BLM) should form a standing committee with representation from all sectors of the helium market, including scientific and technological users, to regularly assess

whether national needs are being met, to assist BLM in improving its operation of the Federal Helium Reserve, and to respond to other recommendations in this report.

Conclusion. The strategic reserve is a finite resource and will one day be depleted. However, the helium needs of participants in the in-kind program will continue and alternative sources will have to be found for those in-kind uses that have no substitute. One possible source is helium extracted from federal lands, such as the Riley Ridge area in Wyoming. BLM could continue to serve as the operator of an in-kind program by handling Riley Ridge crude helium in a manner similar to that currently in place for indirectly using Bush Dome Reservoir crude helium reserves to satisfy the needs of in-kind users.

Recommendation 10. The Bureau of Land Management, in consultation with the Office of Science and Technology Policy and relevant congressional committees, should commission a study to determine the best method of delivering helium to the in-kind program, especially after the functional depletion of the Bush Dome Reservoir, recognizing that this will not happen until well after 2015.

Concluding Remarks

Having heard testimony from helium users and suppliers, as well as representatives of BLM, the committee was struck by the need to commence action now in order to secure a helium supply in the not-too-distant future when the prescriptions of the 1996 Act expire. The legislative framework for the operation of the federal helium program is silent as to the management of the Bush Dome Reservoir and the Helium Pipeline after 2015, when substantially all of the federally owned crude helium stored in the Bush Dome Reservoir is mandated for disposal. It is virtually certain that much more than 600 MMcf of crude helium will remain in the Bush Dome Reservoir at the end of 2015 and most current projections foresee that this target will not be achieved until 2020 at the earliest. If BLM is unable to develop a market-based approach to pricing its crude helium sales, 2016 may arrive with more than 600 MMcf in the Reservoir and incomplete retirement of the facilities' debt. Even if it does manage to pay off its debt by 2015, given uncertainties about future prices and the capacity of the Helium Pipeline, several important questions remain to be answered: What is to be done with the remaining crude helium? How will BLM operations beyond 2015 be financed? Should the Federal Helium Reserve, either federal or private, as appropriate, continue to exist once the BLM debt to the U.S. Treasury has been retired? Before a decision is taken, any future operations in the reserve, which would probably continue to be at Bush Dome, would need to be studied. For the study to be feasible, the refiners on the Pipeline would need to give their support.

The committee is not in a position to answer the many questions that abound about the future of the Helium Reserve because doing so would involve policy and/or legislative decisions beyond the scope of this study's mandate. However, the critical users of helium in the United States, whose interests are the focus of this report, deserve having these questions and others like them answered.

- If BLM can retire its debt to the nation before selling off all but 600 MMcf, should it cease recovery operations and, possibly, leave the remaining helium stored in the Bush Dome Reservoir as a strategic helium reserve for the country? Since the sales of the hydrocarbons that are extracted along with crude helium have significantly reduced the debt, it is quite possible that BLM will be able to pay down the debt early, especially if it sells at a higher market price.
- Can the legislation requiring helium recovery in equal annual amounts be changed to reflect how reservoirs actually perform (highest withdrawal rates in the initial years and much reduced withdrawal rates in the final years)? Such a change in legislative operational requirements could reduce but not eliminate expensive efforts to increase withdrawal rates from the Bush Dome Reservoir between the time this report is written and 2014, the final year of the stored helium recovery program.

That said, the committee has come to the following conclusion on long-term U.S. needs. The limited supply of helium from subsurface resources calls for prioritizing its use and disposition to maximize national security, space, and scientific research leadership over the long term and to promote efficient development of helium resources. Ideally, this effort would be a worldwide collaboration, although it is expected that individual countries would be pursuing somewhat different goals. The committee recognizes that the United States must take action in the following areas:

- Make U.S. helium available, to the extent possible, for important domestic needs after the functional life of the Federal Helium Reserve is over. Because this will undoubtedly mean substantial increases in price, those funding nationally significant uses of helium will have to be committed to providing the necessary funds to purchase helium.
- Promote the discovery in North America of new and significant helium resources.

The committee concludes that without such careful and purposeful management of the Federal Helium Reserve, the Reserve is not being exploited as well as it could be for the public good. It is clear to the committee that selling substantially all of the federally owned crude helium in the Reserve in the manner prescribed by the 1996 Act has had and will continue to have an adverse effect on U.S. users of helium.[19] A new approach is required, and the committee believes that the actions recommended here are the first steps in that direction. The committee also concludes that regular and careful reviews of the program by an independent body would be valuable. Moreover, the affected interests are sufficiently broad that agencies other than BLM (including research funding agencies, the White House Office of Science and Technology Policy, and congressional committees) must be involved in periodic reviews and in the establishment of a long-term strategy for U.S. helium reserves in the Bush Dome Reservoir and elsewhere. The stewardship of this valuable national asset could be much improved.

[19]In making this determination, it is not the committee's intent to state that the decision made in 1996 to substantially sell off the Helium Reserve was wrong. Rather, the focus of this report is on the present and near future. The committee believes that because conditions have changed, the 1996 Act no longer meets the nation's needs.

2

The Helium Supply Chain

INTRODUCTION

The supply chain for helium, beginning with its origins as a constituent of natural gas through its production and delivery to the hundreds of thousands of helium users around the world, is a complex structure. Its makeup and how it will impact and be impacted by committee recommendations are discussed in this chapter. The discussion begins with raw helium sources, focusing on the conditions that must be met before helium extraction facilities are developed. This is followed by a short discussion on how the raw helium is first processed into crude helium and then refined into the product that eventually is delivered to end users. The primary and secondary distribution systems are then described, first for the United States and then for the rest of the world. Particular issues that relate to the focus of this report are highlighted throughout the chapter.

RAW HELIUM SUPPLIES

Currently, the only commercially feasible source of helium is its extraction from natural gas, and then only when the following conditions are satisfied:

- The natural gas fields in question are of sufficient volume that the amount of helium projected to be extracted justifies the expense of installing helium extraction facilities;

- The concentrations of helium in the fields are from 0.04 to 0.65 percent; the concentration at which extraction is economically feasible depends on how the natural gas will be processed;
- Any refined helium to be produced will have affordable access to worldwide markets; and
- The overall economics of the project, not just the volume of gas, justify the capital required to install and maintain the extraction facilities.

These conditions have been satisfied in the United States for many years and are now being satisfied in several other countries, including Poland, Russia, Algeria, Qatar, and China, with a new source currently being developed in Australia. It is likely that helium will also start to be extracted from natural gas in Canada, Indonesia, and Iran during the coming decade, with additional sources being developed during the next 25-50 years. More detailed information is provided in Chapter 4 about the estimated quantity of raw helium in these sources, both now and in the foreseeable future, and the current and future global capacities for extracting helium from them.

Figure 2.1 shows the locations of important international helium recovery and production operations as well as the destination of shipments of helium to significant markets around the world, details of which are discussed later in the chapter.

The three most important natural-gas-processing operations from which helium is extracted are these:

- The processing of natural gas to extract natural gas liquids (NGLs) such as propane, ethane, butane, and benzene for fuels and as feedstocks for petrochemical production. This is the helium recovery, processing, and liquefaction basis for the midcontinental helium operations in the Hugoton-Panhandle fields that span Kansas, Oklahoma, and Texas, and were the basis for the U.S. government's recovery of crude helium during the strategic recovery program through the 1970s. They are discussed in more detail in Chapter 5. Figure 1.3 shows the location of important sources of helium in the United States.
- The extraction of natural gas streams rich in CO_2, where the CO_2 is used for enhanced oil recovery (EOR) and the methane in the natural gas is piped to methane markets. This is the process on which ExxonMobil's large helium operation in the Riley Ridge fields in Wyoming is based.
- The processing of natural gas into liquefied natural gas (LNG) for shipment to many of the world's energy markets. This is the basis for the large helium recovery, processing, and liquefaction operations in Algeria and Qatar and will support future helium recovery operations in those countries and elsewhere.

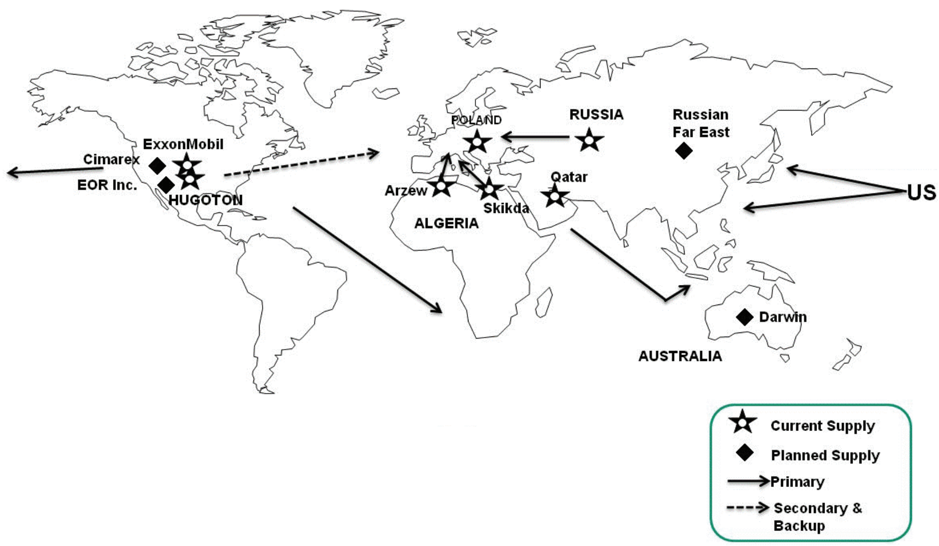

FIGURE 2.1 Origin and destination for large segments of the 6.5 Bcf/yr helium market in 2008 (the following figures are the approximate amount of helium consumed in each region): United States, 2.8 Bcf; Canada and South American, 0.3; Europe, 1.7; Asia, 1.5; Africa, Middle East, and India, 0.15. SOURCE: CryoGas International.

HELIUM PRODUCTION

The first part of the helium supply chain involves processing the natural gas to remove the raw helium and impurities, and then processing it further to get refined helium. Box 2.1 describes these processes in more detail.

In facilities not connected to the Helium Pipeline, the processing of natural gas to remove the crude helium and then to produce refined helium typically takes place in a single plant where the crude and refined processing are closely connected. However, the helium extraction and refining facilities connected to the Helium Pipeline have been constructed such that extraction plants can deliver crude helium directly to a refining facility or to the Helium Pipeline, and the refining facilities can, by the same token, process crude helium supplied either from an adjoining extraction facility or from the Helium Pipeline.

The natural gas companies that produce the crude helium have operations involved in natural gas recovery, pipeline transportation, and processing for NGLs. The helium refining companies operating in fields connected by the Helium Pipeline typically have long-term—15- to 25-year—crude helium supply contracts with the industrial gas refiners that have been operating along the Helium Pipeline

BOX 2.1
Producing Helium from Natural Gas

Processing of the helium found in natural gas occurs in two stages. The first step is extracting crude helium (which, after extraction, typically is composed of 50-70 percent by volume of helium) from the stream of natural gas. The second step involves further refining the crude helium to produce purified helium of different commercial grades.

Crude Helium Production

The specific procedure followed for extracting crude helium from natural gas depends on whether the natural gas is being processed to produce methane and natural gas liquids (NGLs) or other source gases such as CO_2 or is being converted into liquefied natural gas (LNG). The extraction process typically requires three sequential operations. First, impurities such as water, CO_2, mercury, and hydrogen sulfide are removed from the gas using various extraction and absorption processes. Second, high-molecular-weight hydrocarbons are separated by passing the gas stream through a bed of activated carbon and having the heavier hydrocarbons affix to the activated carbon surfaces. Finally, cryogenic distillation separates and removes most of the remaining methane gas. The end product is a gas mixture typically containing 50-70 percent helium, with the remainder primarily nitrogen and smaller amounts of argon, neon, and hydrogen.

In the United States, before natural gas containing raw helium will be considered "crude helium," it must have a helium concentration of more than 50 percent and only limited amounts of certain impurities such as H_2, which must be less than 20 parts per million (ppm). These specifications were set early on by the Bureau of Mines, BLM's predecessor in managing the Federal Helium Reserve, and allow the crude helium to be stored in the Bush Dome Reservoir and then successfully withdrawn, compressed, processed through the Helium Enrichment Unit and supplied for processing to the refining and liquefaction plants along the Helium Pipeline.

Refined Helium Production

Final purification of helium usually is done in stages, with the precise method dependent on the crude helium's purity and intended use. A typical process involves first cooling the crude helium to temperatures at which nitrogen and methane condense into a liquid. That liquid is drained off, leaving a gas of approximately 90 percent helium. The gas is then warmed, combined with air enriched with oxygen, and passed over a catalyst that allows the oxygen and hydrogen to combine into water vapor, which is condensed and drawn off. The remaining gas then enters a pressure swing adsorption (PSA) unit that ultimately yields helium at better than 99.99 percent purity. Further cryogenic adsorption processes can increase helium purity to as high as 99.9999 percent.

LNG Processing

The process for extracting helium from LNG tail gases is similar to the final purification steps just discussed, since the gas remaining after liquefying methane is similar to the crude helium that is the end product of the cryogenic distillation process discussed above. Passing the gas through catalytic adsorption and PSA units produces helium up to 99.9999 percent pure. The end product of the refining process is liquefied helium.

since the 1960s. These helium refiners are leading international companies in the industrial gas industry, and each has developed or licensed significant helium-processing and low-temperature cryogenic liquefaction technology. These same companies also are responsible for the design and construction of most of the world's helium refining plants and for virtually all of the primary distribution of the refined helium gas and liquid from the United States and international plants to the largest direct users of helium and to their own or other distributors' redistribution centers around the world. Details of this distribution network are discussed in the following section.

REFINED HELIUM SUPPLY CHAIN

This section discusses the network that has developed for supplying refined helium to all but the largest end users. Because most of the refined helium supplied to the world originates in the United States (over 75 percent in 2008), this section focuses on that network.

Figure 2.2 shows a simplified schematic of the U.S. helium supply chain. The chain starts with the extraction and processing of helium from natural gas and proceeds to the purification and production of refined helium in liquefied form, both processes discussed in the preceding section. The next link in the supply chain is placing the liquid helium into the primary distribution system, where it is trucked to very large customers, redistribution/transfill depots (referred to as "transfills" throughout this report), and ports serving ocean shipping to foreign markets. The final phase of the supply chain is from U.S. redistribution depots to a wide variety of end users.

Primary Distribution of Liquid Helium

Primary distribution of liquid helium, from the refining plants to large liquid helium customers, to transfill depots, and to U.S. ports for export to foreign markets, is performed in very large tankers (1.5 MMcf capacity) or in specially designed ISO liquid helium containers (1.1 MMcf capacity). Figure 2.3 shows a typical liquid helium plant and the types of containers used to transport helium from helium refiners to the next leg of the distribution network.

ISO containers permit interchangeable deliveries directly to very large volume U.S. users and to U.S. ports for ocean shipping to Europe, Asia, and other parts of the world for secondary redistribution in those markets. The cost of this cartage can be quite high as the tankers and specially designed ISO containers are very costly triple-walled, high-vacuum, superinsulated containers.

Exported liquid helium is shipped as deck cargo on container ships in ISO containers of the above description; the maximum holding time without signifi-

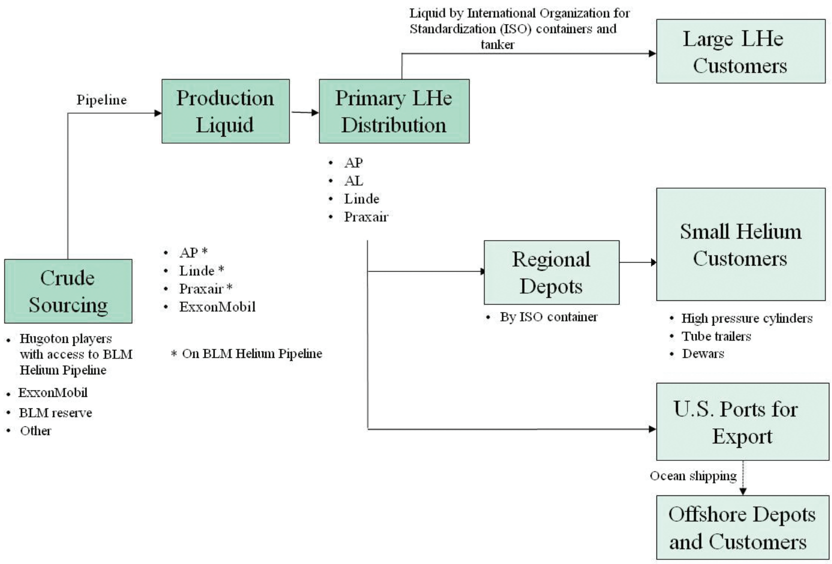

FIGURE 2.2 The helium supply chain in the United States, from the sourcing of crude helium to the production of refined liquid helium (LHe) to final delivery to customers. The principal companies engaged in each link of the supply chain are identified: AP, Air Products and Chemicals, Inc.; Linde, Linde North America Inc., a member of the Linde Group; AL, Air Liquide; Praxair, Praxair, Inc. SOURCE: CryoGas International.

FIGURE 2.3 U.S. liquid helium plant (in the rear), helium tankers (attached to the truck and on the left), and International Organization for Standardization (ISO) containers for overseas shipment (middle and right). SOURCE: Air Products and Chemicals, Inc.

cant helium loss is 30-45 days. In the United States and Europe, gas and liquid are shipped to customers with large volume requirements in tube trailers (as a gas) and in tankers and ISO tanks as liquid helium. Tankers drop off or fill ISO tanks for a few very large customers (for example, General Electric's MRI manufacturing operations at Florence, South Carolina). Some medium-sized customers are served directly from refiners' plants by gas in large tube trailers if the distribution distance favors that channel, generally less than 500 miles from the plant.

An important part of U.S. primary helium distribution is the delivery of ISO tank liquid helium to the ports of Newark, New Jersey, and Long Beach, California, for ocean shipment to ports around the world. Those ports serve large helium markets in South America, Europe, the Middle East, and Asia. Primary redistribution depots are located at these ports for direct transfill to the kinds of distribution equipment noted elsewhere in this chapter or for routing in ISO tanks to large helium customers inland.

The three main international companies in the supply chain are involved in all stages, from producing refined helium to servicing the end-use customer: Air Products and Chemicals, Inc., Linde North America, Inc., and Praxair, Inc. ExxonMobil is the largest liquid helium producer, with its crude feed coming from helium-rich CO_2 and methane gas fields in Wyoming. Airgas, Inc., Air Liquide, Matheson-Trigas, Inc., Air Products, and Praxair are buyers of liquid helium from ExxonMobil and are the most important players in the primary and secondary parts of the supply chain. Air Liquide, Air Products, Linde, Matheson-Trigas, and Praxair are the main companies involved in primary worldwide helium distribution. These companies also have significant access to the international end-use customer population and are responsible for many of the technology and applications developments in helium use and conservation.

Most of the industrial gas and therefore helium markets of the United States, Europe, South America and Asia are dominated by the five large international gas companies that control the worldwide market for helium—Air Products, Linde, Praxair, Air Liquide, and Taiyo Nippon Sanso. Because independent distribution and service in these important regions are limited, the barrier to entry in the distribution to and service of even the smallest of helium customers is very high.

Secondary Distribution of Helium

Secondary distribution channels handle most of the helium delivered to end users in the United States. The companies in this channel include the same large industrial gas companies that dominate primary distribution mentioned in the preceding section and many private, independent industrial, medical, and specialty gas distributors. There are more than 800 such distributor-type companies in the United States.

While most helium is transported as bulk liquid to the very large volume customers and to transfill and redistribution depots, U.S. industrial gas distributors deliver to the small and medium volume end users in a wide variety of smaller containers:

- High-pressure steel cylinders containing 10 to 300 cf of gaseous helium;
- High-pressure tube trailers containing 30,000 to 180,000 cf of gaseous helium;
- Dewars containing 50 to 500 L of liquid helium; and
- A variety of specialized containers for gaseous and liquid helium for specific applications.

Figure 2.4 illustrates some of the many storage containers in which liquid and gaseous helium are delivered to end users.

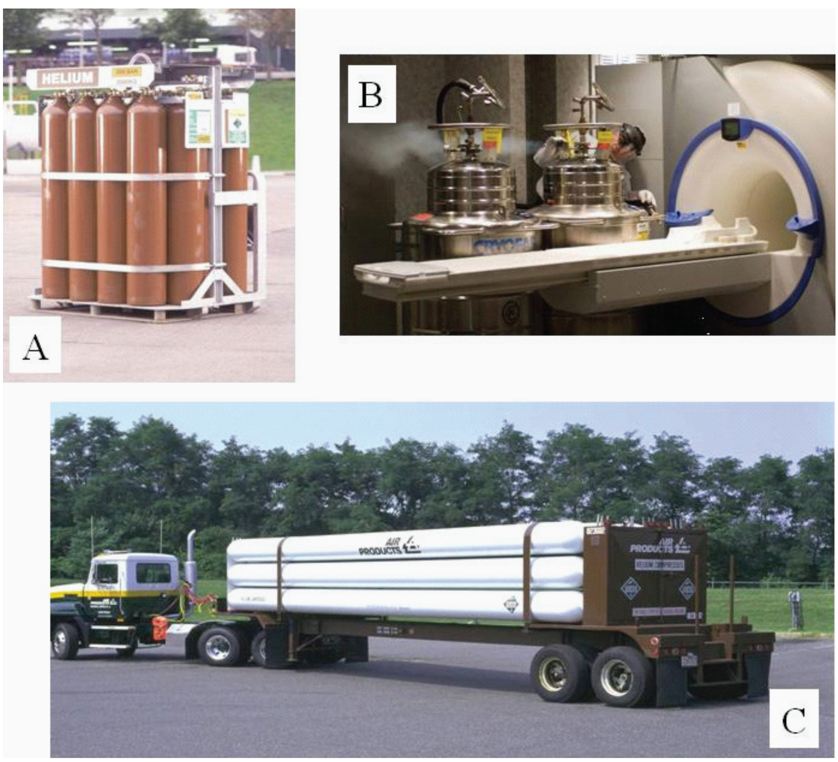

FIGURE 2.4 Small-volume helium storage containers: (A) cylinders of gaseous helium; (B) dewars of liquid helium (appearing in the background); and (C) high-pressure tube trailer carrying gaseous helium. SOURCE: Air Products and Chemicals, Inc.

Many of the contracts for the supply of refined gas and liquid helium to very large customers take the long-term form of crude-supply contracts. Terms of sale to other customers might be under contracts of varying lengths and subject to varying pricing terms. Sales of helium in cylinders to smaller customers typically are spot sales, with helium delivered when needed by the customer.

The pricing of helium to end users is complicated by the wide variations in transportation and packaging costs associated with each user. There are distinct costs associated with the packaging and delivery for each of the above containers. The pricing must include the costs of transporting helium along the primary distribution channels and then delivering it to transfill depots for secondary distribution or to ports for ocean shipping to foreign customers. Estimating the costs and therefore the amount to be charged for primary distribution to customers in other countries is complicated by the high cost of ocean transport and the wide variations encountered, and the subsequent trucking costs from the foreign receiving depot to inland transfill points.

3

Demand for Helium

INTRODUCTION

Helium is perhaps best known to the general public for its use in party balloons and at the Thanksgiving Day parades in New York City and elsewhere. However, the unique physical and chemical properties of helium make it valuable and indeed irreplaceable in a wide variety of scientific, biomedical, industrial, and national strategic and defense applications, all of which are discussed in this chapter. The first section provides an overview of the demand for helium in the United States and other countries since 1990 and the second a forecast of demand for helium through 2020. The chapter then looks at individual applications of helium, first discussing general economic considerations for different applications and then summarizing the trends in the various applications in the United States. The final section discusses the principal categories of helium usage in more detail, including cost-effective conservation measures available now, emphasizing aspects of each use that are particularly pertinent to this study: How much helium does a category consume? What alternatives are available to these users if helium prices continue to rise and helium supplies are interrupted?

OVERVIEW OF U.S., FOREIGN, AND WORLDWIDE DEMAND TO 2008

Figure 3.1 shows the historical development of refined helium demand in U.S. and foreign markets from 1990 to 2008.[1] Worldwide helium demand grew from

[1]USGS, 2008, USGS, 2009. See footnote 4 in Chapter 1 for a list of the units used in this report to report helium volumes.

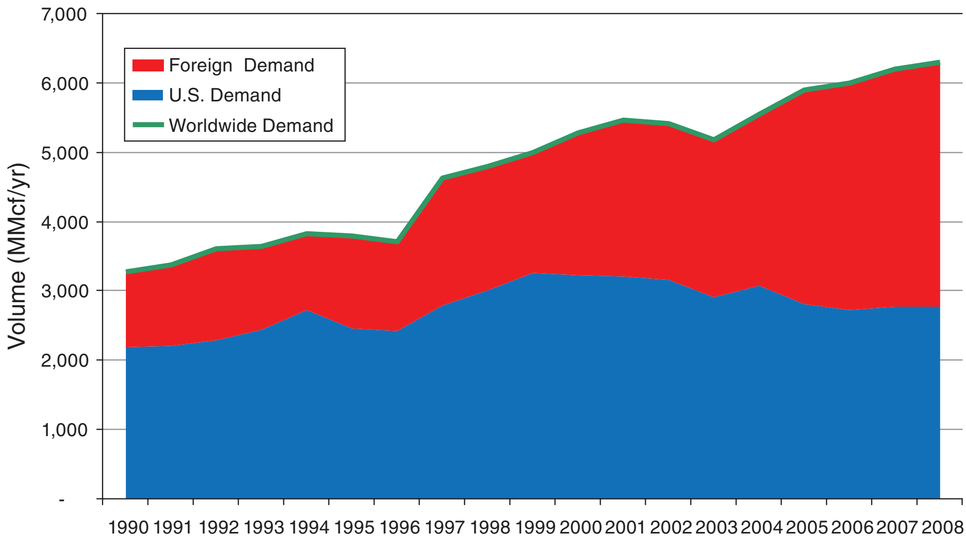

FIGURE 3.1 Consumption of refined helium in the United States (blue), in other countries (red), and worldwide (green line) for the years 1990 through 2008. SOURCE: Cryogas International.

3.28 Bcf in 1990 to 6.3 Bcf in 2008—a growth rate of 3.6 percent per year—and included a growth spurt of 7.8 percent per year between 1996 and 2001. Historically, the United States has been the consumer of most of the helium produced each year, but consumption in the United States has flattened in recent years, while consumption outside the United States has grown significantly (see Figures 3.1 and 3.2). The consumption of helium outside the United States has exceeded domestic consumption since 2007.

ESTIMATE OF DEMAND TO 2020

As noted in Chapter 1 in the section entitled "Review of the 2000 Report's Conclusions," the lack of sufficient data, especially on foreign markets, makes it difficult to forecast demands for helium beyond the near term. Accordingly, any attempt to determine where the helium market will be more than a few years into the future should be treated as a rough estimate rather than an accurate prediction. With that proviso, Figure 3.3 estimates demand for refined helium in the U.S. and foreign markets through 2020. A drop of 10 percent in worldwide demand, or 650 MMcf, is forecast for 2009 owing to the worldwide recession. In addition, this short-term scenario assumes some reduction in both U.S. and foreign use of helium from invigorated recycling of spent helium and conservation owing to

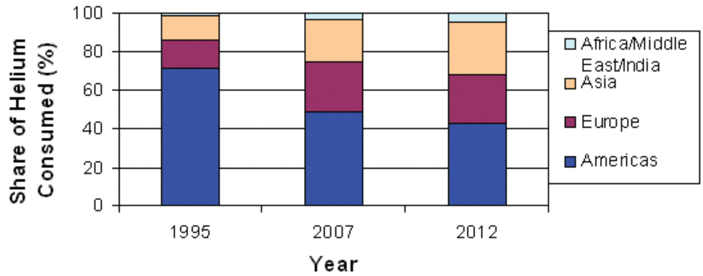

FIGURE 3.2 Helium demand among regions of the world over time. In 1995, the total volume sold was 3.750 Bcf; in 2007, it was 6.335 Bcf, and in 2012, it is expected to be approximately 6.5 Bcf. SOURCE: Cryogas International.

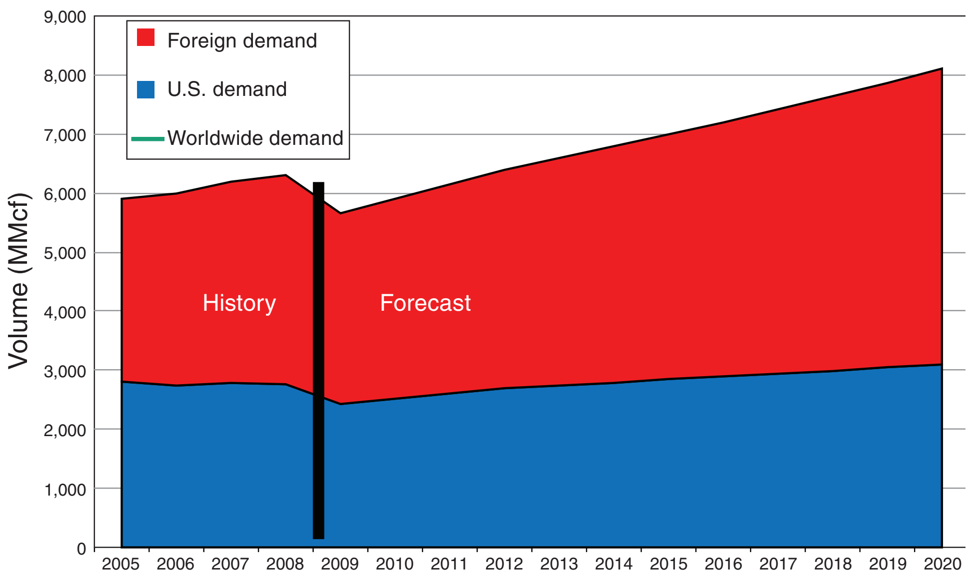

FIGURE 3.3 Actual (2005-2008) and projected (2009-2020) market demand for refined helium in the United States (blue), in other countries (red), and worldwide (green line). See text for a discussion of estimated future demand.

the significant increase in the price of helium in recent years (see Figure 1.5). The United States will experience most of that drop, while Asia is forecast to experience continued growth in demand, if at a slower rate.

Estimates for the years beyond 2012 are based in part on an informal poll of representatives of the principal companies involved in the helium supply market and the knowledge of committee members involved in the industrial gas market and in part on the assumption that the global economic downturn will not extend beyond 2010. That estimate suggests that worldwide demand will recover to 2008 delivered volume levels by 2012 and that demand will continue to grow worldwide at growth rates of approximately 3 percent per year from the end of 2012 through 2020. That 8-year run of growth is forecast to include a rate of slightly less than 2 percent per year for the United States and an almost 4 percent per year growth rate for the aggregate markets outside the United States.

ECONOMIC CONSIDERATIONS

Continued demand for helium by a particular user or class of users will depend on a variety of factors, but for many users, helium is unique and must be used, regardless of price. Price does, however, play the key role in allocating its limited supply to those who place the highest value on its use. Further, for all helium users, technologies that conserve and/or recover helium can reduce the amount of helium consumed by as much as a factor of ten and it is expected that continued high prices will induce reduced usage, either through conservation or, where appropriate, through substitution of other materials.

For some applications, other gases can replace helium, but other applications rely critically on helium's unique properties, and there are no alternatives. Applications in the first category, where substitutes for helium might exist, include the following:

- *Lifting.* For these uses, where low density is the only requirement, hydrogen is sometimes substituted if safety concerns can be met.
- *Welding.* Here, chemical inertness is the key property. For processes such as gas tungsten arc welding—a critical process applicable to reactive metals such as stainless steel, titanium, aluminum, and others in high-value, high-reliability applications—Europe mostly uses argon, while the United States uses helium.
- *Semiconductor and fiber optics manufacturing.* In these applications, high thermal conductivity is the important property. Often, hydrogen may be substituted.

In the above applications, economics, market conditions, availability, safety, and legislation can influence the choice among helium and other gases. In contrast, other applications require the unique properties of helium, typically relying on the extremely low boiling point of liquid helium to achieve a desired result. These applications include the following:

- *Purging.* Here, entities such as the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD) must purge liquid hydrogen (LH_2) and liquid oxygen (LOx) fuel tanks or systems that may be at liquid air temperatures or colder. Although gaseous hydrogen might have the right physical properties for use in LOx systems, its reactivity with oxygen precludes its use. Nitrogen is not desirable because nitrogen might contaminate the LOx. In LH_2 environments, all gases other than helium and hydrogen would freeze, clogging fuel lines and systems and rendering the rocket engines nonfunctional.

- *Superconductivity*. One such use is in the superconducting magnets that all medical magnetic resonance imaging (MRI) machines employ. Current materials and technologies dictate that only helium can act as the crucial refrigerant.
- *Basic research*. Here, no other substance can be used as a refrigerant to achieve temperatures from 4.2 K above absolute zero down to millikelvins (thousands of a kelvin).

Because price plays such a fundamental role in demand and the 1996 Act has had a profound effect on the price of crude (and therefore refined) helium, this chapter catalogues, where information is available, the existence, usefulness, and cost of substitutes, as well as the potential for recovery, recycling, and other conservation strategies in different markets. Ideally, quantitative estimates of the elasticity of demand with respect to price would be provided for these various applications but since the data are not adequate the discussion remains mainly qualitative.

HELIUM APPLICATIONS IN THE UNITED STATES

Turning to consumption in the United States, Figure 3.4 illustrates domestic helium usage, by general application categories, for 1975-2008. Figure 3.5 provides the latest public data on the share of total domestic usage of helium accounted for by each application in 2007. The remainder of this chapter discusses the applications for which data have been collected, with alternatives and conservation measures provided where possible.

Cryogenic Uses

The largest share of helium in the United States is accounted for by cryogenic applications, which take advantage of helium's uniquely low boiling point. Cryogenic uses range from medical uses and high-technology manufacturing to science and technology investigations in academic laboratories.

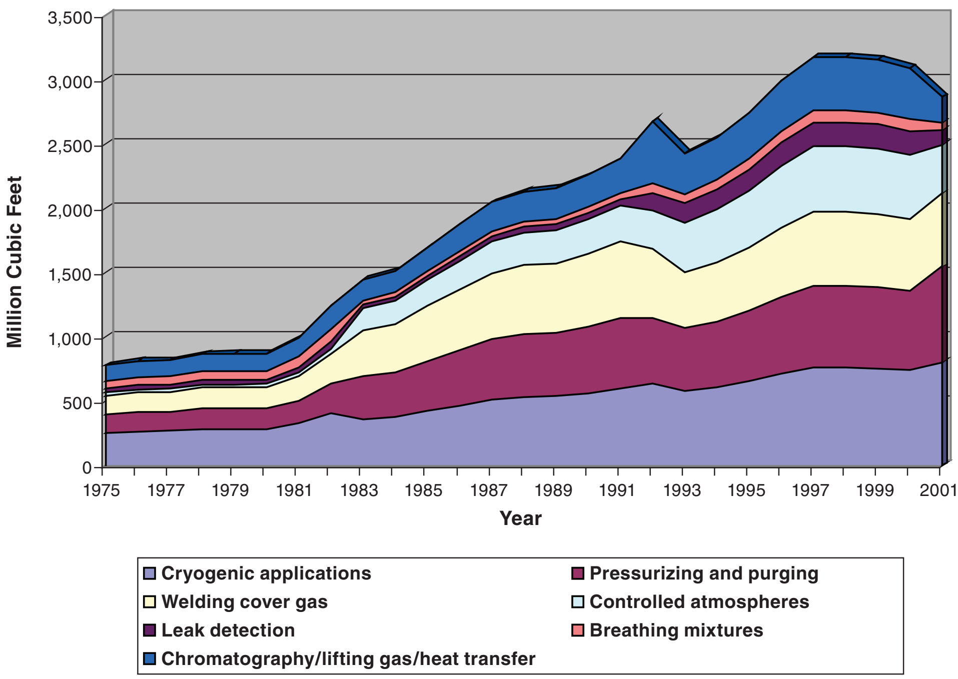

FIGURE 3.4 End uses of helium in the United States, by application, 1975-2001. SOURCE: USGS, 2005b.

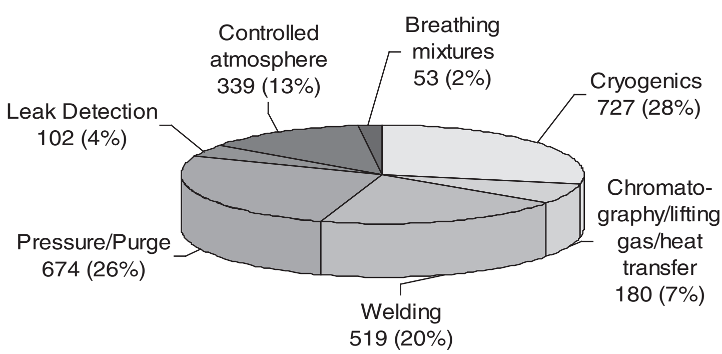

FIGURE 3.5 Estimated end uses of helium in the United States for 2007. The shares are the percent of U.S. consumption by volume (MMcf). SOURCE: USGS, 2007.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a widely used non-x-ray-based technique that provides extremely detailed internal in vivo images of body structure. An MRI apparatus uses a strong magnetic field to align the nuclear magnetic spins of hydrogen atoms in a body, then drives the aligned hydrogen atoms at radio frequencies, and after detecting the properties of the aligned, driven atoms, uses tomography to process the density- and environment-dependent response, producing a noninvasive three-dimensional image. The only commercially viable source of the large (0.5-3.0 tesla) magnetic fields required for this process is a superconducting magnet contained in a cryostat—a container designed to thermally insulate the liquid-helium-cooled superconducting magnet and the liquid helium source.

The availability of helium at low prices and the stability of the market over the years contributed to the rapid growth of MRI as a diagnostic tool in the 1980s, and these tools have made and continue to make a significant contribution to health care in the United States. There are now more than 22,000 machines in the United States and abroad and that number continues to grow. In addition to their use for medical diagnostics, MRI devices frequently are used in research laboratories in chemistry, biology, neuropsychology, and the medical sciences.

At the present time there is no substitute for helium in this application. If large magnet systems with high-temperature (T_c) superconductors (materials that are superconducting at relatively high temperatures) could be built, the demand for helium in this application would be reduced greatly. However, these reductions will occur only if such materials remain superconducting above the boiling point of nitrogen (77 K), allowing the magnets to be cooled with liquid nitrogen instead of liquid helium. In the committee's judgment, developing such materials and incorporating them into economically competitive devices is not likely to happen for 5 to 10 years, if at all.

In recent years, manufacturers of MRI systems have adapted or developed technologies that significantly decrease the consumption of liquid helium to operate these devices. The advances include cryostats with superior thermal efficiency and cryocoolers that capture vented helium and reliquefy it, as well as changes in the design of the equipment that reduce the size and weight of the materials that need to be cooled. As a consequence, new systems consume dramatically less helium than earlier systems. With proper market signals these users can be expected to recycle even further as the price of helium rises.

Fundamental Research

The second most important cryogenic application of helium is in research laboratories. In discussing how helium is used in research and the users' needs, it is convenient to divide research laboratories into large-scale and small-scale facilities. All such facilities located in the United States are supported with substantial U.S. government funding.

Large-Scale Laboratories Large-scale facilities are characterized by signature research tools used by many, often hundreds of, research groups. All such facilities located in the United States are supported with substantial U.S. government funding and typically are located in national laboratories. The principal use of helium in these laboratories is to cool superconducting equipment for accelerators, particle detectors, and research magnets. In the United States, the largest particle accelerator facilities exist at Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Argonne National Laboratory, Thomas Jefferson National Accelerator Facility, and Los Alamos National Laboratory, among others. Europe also has several large particle accelerators, including the Large Hadron Collider (LHC) at Organisation Européenne pour la Recherche Nucléaire (CERN), situated on the Franco-Swiss border, and the Deutsches Elektronen Synchrotron (DESY) in Hamburg, Germany. Large-scale particle and nuclear physics research is conducted throughout Asia, particularly in Japan (at the Laboratory for High-Energy Physics [KEK] and J-PARC facilities), China, Taiwan, and South Korea. Also, major projects utilizing superconducting technology based on helium are underway, including superconductivity research projects by the U.S. Air Force at the Edwards and Kirtland air force bases and superconductivity power systems research at Wright-Patterson Air Force Base. Annual usage at these Air Force facilities and other DOD-supported locations (including various laboratories and universities with federal contracts) is approximately 64,000 liters per year. Additional usage is anticipated at the International Linear Collider (ILC).

These accelerator facilities rely on superconducting magnets, cavities, and other superconducting components to produce and maintain high-energy particle beams. The superconducting components used in these facilities must be kept at very low temperatures, which in practice can be achieved only with liquid helium because of its low boiling point and high thermal conductivity. Large amounts of helium are often required at start-up in particle accelerators because liquid helium must be distributed along the entire length of the machine, which can be many kilometers. As just one example of the amount of helium required for these facilities, the amount of helium required to cool down the LHC facility is approximately 22 MMcf (Bhunia, 2003) and the ongoing inventory will be more than 2 MMcf (Maglioni and Parma, 2008). Superconducting particle accelerators recirculate their helium in a closed loop. As a result, after being filled with helium, the accelerators only need further helium to replace losses due to leaks, accidents, power failures, and so on. It is expected that substantial quantities of helium will be required for the development and operation of future particle accelerators.

Helium is also used in large-scale research laboratories because it exhibits unique superfluid properties below 2.17 K (achieved by pumping to low pressure), including extremely high thermal conductivity. This makes it useful for cooling superconducting radio frequency (SRF) cavities. A significant supply of helium is required for the development of such cavities for current and future accelerator projects because the complexity of the systems and the present cost of helium make it most practical to vent used helium gas to the atmosphere. This practice could change if economic drivers and government incentives were brought to bear.

The third principal use in this category is for research magnets. The only facility of its kind in the United States, the National High Magnetic Field Laboratory, is the largest and highest-powered magnet laboratory in the world. It has components at Florida State University in Tallahassee, Florida; Los Alamos National Laboratory in Los Alamos, New Mexico; and the University of Florida in Gainesville. The laboratory is a national resource for research in physics, biology, bioengineering, chemistry, geochemistry, biochemistry, and materials science and engineering. Liquid helium is used extensively to cool research superconducting magnets and experiments at all three facilities. Some recovery and reliquefaction facilities have been successfully installed and are cost effective. These recovery operations have cut helium losses due to venting from 50,000 liters of liquid per year to fewer than 5000 liters of liquid per year.

Small-Scale Laboratories A typical small-scale facility is operated by an individual group or a small collection of research groups in an academic setting or at a national laboratory. These research activities are led mostly by individual faculty and staff members in the 100 or so research universities and national laboratories across the United States and, occasionally in smaller regional colleges. Such research efforts typically comprise a lead investigator and one or two graduate students and postdoctoral research fellows. Individually and collectively, these small users are at the mercy of prices and markets driven by larger users.

The research conducted in these laboratories can be similar to that in large-scale facilities but it covers a wider range of fields and research interests, including materials, condensed matter, chemistry, biology, biophysics, neuropsychology, nanotechnology, observational astronomy, and astrophysics. In general, cryogenics in these facilities is used to provide low temperatures for measurements, to cool detectors to either reach operational temperatures or reduce noise, or to cool research superconducting magnets. Liquid helium is the most widely used cooling agent (liquid nitrogen is second) and is often the only way to reach the necessary low temperatures.

In addition to the environment in which research is conducted with liquid helium, small laboratories rely on liquid helium to operate diagnostic and measurement tools. Among the more important of those helium-cooled tools are superconducting quantum interference devices (SQUIDs). SQUIDs measure extremely small magnetic fields and are used in a wide range of studies, from biological research on brain activity to the assessment of materials characteristics. Devices used in astronomy and astrophysics studies also depend critically on liquid helium. The acquisition of extremely weak signals in several disciplines relies on helium-cooled detectors to reduce thermal and electrical noise. Such detectors, developed as basic research tools, are commonly used for national defense needs as well, such as for detecting submarines by the military.

Most of the research and medical systems discussed here that require liquid helium either are commercially produced or are under development for future commercial production. The demand for the systems has, in itself, nurtured a cryogenic research-equipment manufacturing industry in the United States and abroad that is completely dependent on the availability of liquid helium for its continued operations. The above fundamental research uses, critical to U.S. scientific leadership, have few or no substitutes and are largely funded by federal grants. They are severely impacted by high helium prices and market volatility. Although helium can be economically recovered in a number of these applications, the unavailability of funding, especially for small-scale users, may limit or preclude recovery.

Industrial Cryogenics

Semiconductor Processing Liquid helium is used in the manufacture of semiconductor single-crystal boules via the magnetic-field-applied Czochralski method, where helium-cooled superconducting magnets mechanically stabilize the melt during the pulling process. Helium is critical to this process and, by extension, to the semiconductor industry. In addition, some fabrication facilities require processing in ultraclean environments or under ultrahigh vacuum. Cryopumps cooled to liquid helium temperatures are one of the more widely used means of reaching those high vacuum conditions.

Superconducting magnets using closed-cycle systems can replace total-loss systems economically. The expected reduction in helium consumption for these systems should be similar to that of research magnets, on the order of 90 percent.

Other Industrial Cryogenic Uses Other activities using helium are plasma etching and vacuum pumping. In the latter, liquid-helium-cooled surfaces cryopump gases. Recycling is possible for each of these processes. Indeed, magnet systems employing cryocoolers dedicated to crystal growth are available commercially, and commercial cryopumps are all closed cycle.

With proper market price signals, the bottom line should spur these market users to invest in recycling.

Pressurizing/Purging

The low boiling point and chemical inertness of helium make it a unique purge gas for the second-largest category of helium use, liquid hydrogen/liquid oxygen-fuel (LH_2/LOx) rocket propulsion systems. The principal U.S. users are NASA and DOD. Their usage is expected to continue for the foreseeable future. Current examples of main (first-stage) LH_2/LOx engines include the space shuttle main engines (SSMEs), the Delta IV rocket's RS-68 engines, and the European Space Agency's (ESAs) Ariane 5 Vulcan engine. Other launch vehicles, such as the Centaur, use LH_2/LOx engines in the upper stages but their helium usage is much less than that of the main engines mentioned. The main driver of helium use for liquid rocket fuel tank purging is the use of liquid hydrogen (LH_2) as a fuel. LH_2 is the second coldest cryogen (boiling point of about 20 K) and is flammable. All other gases but helium and H_2 would freeze, clogging fuel lines and systems, thereby rendering the rocket engines nonfunctional. Helium is also used to purge liquid oxygen (LOx) tanks, not because of freezing issues but because helium does not contaminate LOx. Because it is chemically inert, helium gas is also used to pressurize the (combustible) propellant tanks for rocket engines, to prevent pump cavitation and the collapsing of tanks under vehicle-imposed structural loads, and to eliminate fire and explosion risks. Other minor space applications of helium are to cool fuel-handling systems and to serve as a pneumatic control system gas in spacecraft and other rocket propelled systems.

NASA uses approximately 90-100 MMcf of helium yearly at the two gaseous helium locations where it consumes the most: Kennedy Space Center (KSC) and Stennis Space Center, although these quantities include helium provided to other programs at those centers through support agreements (for example, the Air Force East Coast Delta IV launch operations supported by KSC and Delta IV RS-68 engine testing at SSC). Other, smaller amounts are spread among the various other NASA centers and NASA contractor locations. DOD uses helium for its launch programs separate from that provided by support agreements with NASA, but the quantities are unknown. Examples of DOD's use include the U.S. West Coast Delta IV and Atlas launch operations.

If economic drivers were sufficient, NASA and DOD could greatly reduce helium consumption by recovering helium purging gas or, in at least some instances, replacing it with hydrogen once safety concerns are addressed. However, with current helium availability and price, it is unlikely this will occur in the near future. NASA is increasing its awareness of helium usage, particularly in light of the planned development of the Ares V launch vehicle, which will utilize a LH_2/LOx main stage (requiring helium purging) with a modified version of the RS-68 engines currently used in the DOD Delta IV rockets. DOD is also reviewing helium usage in its Delta IV launch vehicle.

Welding

Because of its historical availability in the United States at relatively low prices, significant amounts of helium are used domestically in welding applications. In this application, helium predominantly serves as a shielding gas, preventing atmospheric contamination of the molten metal and stabilizing the arc. Because of its high ionization potential, high thermal conductivity, and inertness, helium is the optimal gas for some welding applications. However, outside the United States, where helium supplies have been less abundant and more expensive, other gases, principally argon, are used in welding gas mixtures in place of helium.

The welding industry is highly fragmented, so it is difficult to find detailed data organized by welding process and industrial segment. Figure 3.5 shows that welding represented about 20 percent of U.S. consumption in 2007, but it is only a negligible share of the consumption in other countries. The source of this difference seems to be the twofold and threefold higher costs of helium in other countries in the past, leading to the development of alternative welding techniques. These include the application of pulse power sources with other gases to achieve the same results without a dependence on helium. Although no data on market elasticity are available, the demand for gaseous helium in welding seems to be highly elastic, at least when helium prices increase two- or threefold.

One unique niche for helium in the welding industry is as a component of the lasing gas mixture in CO_2 lasers. These mixtures contain nitrogen, helium, and carbon dioxide in roughly a 3:2:1 ratio. It is difficult to recycle this gas as the CO_2 breaks down over time and must be replenished. The costs of operating these lasers are dominated by the cost of electrical power, with helium a minor expense. Solid-state (diode) lasers are capturing a growing share of the laser welding market based on their higher efficiency, so it is hard to predict the long-term demand for helium in CO_2 lasers.

Plasma-arc melting, used to fabricate products made of specialty materials such as refractory metals, is another process requiring helium. The high melting points, extreme hardness, corrosion resistance, and (often) reactivity at high temperatures of these materials make them especially difficult to handle. Plasma-arc melting involves using an electric arc between a water-cooled torch and the material to be melted that enables the melting and casting of that material within an inert environment under extreme conditions. For many of the materials, such as titanium billets for jet-engine components, heating is sufficiently intense that only helium gas provides enough thermal conductivity to control the process. However, for less demanding applications, argon can replace helium.

Controlled Atmospheres

Optical Fiber Manufacture

Helium is a critical element in the production of optical fibers, an important component of the telecommunications industry. Since optical fibers are bent in their application, it is essential that light traveling through the fiber remain within the fiber, thereby providing an uninterrupted signal. To accomplish this, the fiber actually consists of an inner "core" of glass and an outer "sleeve." The difference in the coefficient of refraction between the glass core and the material chosen for the sleeve causes light to bounce within the core, but not to bounce out. Helium is critical to the process of depositing the sleeve onto the core—in any atmosphere other than helium, bubbles tend to get trapped between the core and the sleeve, rendering the fiber unusable. There is no alternative atmosphere for this application.

Helium accounts for a small percentage of the total cost of fiber production. This usage, which is approximately 6 percent of total helium consumption, had been growing by about 5 percent per year. However, several types of helium recovery systems for fiber-optic manufacturing are now available, capable of reducing consumption by more than 95 percent. The impact is not known at present but, again, the profit incentive coupled with appropriate pricing should push manufacturers toward recycling.

Semiconductor Processing

In addition to the cryogenic uses identified in the previous section, more recently, the high thermal conductivity of helium gas has been incorporated into the manufacturing process for plasma screens and to produce higher yields when annealing semiconducting wafers cut from a boule. Helium is also used as a nonreactive gas to flush vessels and containers in the processing of semiconductor chips. Helium gas is used as a heat transfer fluid in rapid gas quenching and in Stirling-cycle engines for the nonexpendable working fluid that makes these engines attractive and efficient for renewable energy applications. Finally, some industrial heat treatments are also conducted in helium atmospheres because its inherently high heat transfer capability cools thick sections rapidly. Helium can be replaced with argon in some of these applications.

Chromatography, Lifting Gas, Heat Transfer

Chromatography

Helium is used for chromatographic separation, predominantly as a carrier gas. Helium is ideal for gas, gas-liquid, and gas-solid chromatography because it is chemically inert and diffuses rapidly. Chromatographic and gas-chromatographic systems are used in the pharmaceutical industry for drug analysis and purification, derivatization, and separation; in the food and beverage industries for separation and analysis; in environmental assessments for air, water, and soil toxin analysis; in medical diagnostics for analyzing the presence of gases in the bloodstream, as an example; and in explosives forensics and petroleum testing. There are no obvious substitutes, given the current state of technology.

Weather, Defense, and Other Lighter-Than-Air Applications

One of the more apparent uses of helium is as a lifting gas. While hydrogen is lighter than helium, helium's chemical inertness makes it safer to use, and so it has replaced hydrogen in most lifting applications. The party-balloon industry uses significant amounts of helium. As a result of the recent tight supplies and increased costs, helium/air mixtures that reduce the concentration of helium in a party balloon by up to 40 percent are becoming more common in the U.S. market. The International Balloon Association provides information on techniques and products to reduce helium usage.

Another lifting use is in the large balloons found at holiday festivities, including the well-known Macy's Thanksgiving Day parade in New York City. News reports that predicted helium shortages might affect the 2006 parade increased public awareness of the tight helium market and related shortages. In 2007, the helium supplier for the parade made the first attempt to recover some of the 400 Mcf of helium used in the parade's balloons that year and expanded that effort in the next year's parade.[2]

Weather balloons use an enormous amount of helium. Twice each day, weather balloons are released from almost 900 locations worldwide, including over 90 sites in the United States and its territories. These balloons are filled with either hydrogen or helium and carry instruments to measure pressure, temperature, and relative humidity as they ascend.[3] This usage alone consumes about 140 MMcf of helium per year, more than the usage by NASA discussed in the "Pressurizing/Purging" subsection.

[2]Available at http://www.linde.com/international/web/linde/like35lindecom.nsf/docbyalias/boc_1157485742146. Last accessed on June 25, 2009.

[3]Available at http://www.srh.noaa.gov/epz/kids/balloon.shtml.

Large balloons used for scientific research can lift payloads as much as 8,000 lb. They can fly up to 26 miles high and remain aloft up to several months, depending on the mission. DOD provides helium for various weather-related missions operated by the Air Force, as well as by the National Oceanic and Atmospheric Administration (NOAA) for its weather missions. The Columbia Scientific Balloon Facility (CSBF), in Palestine, Texas, receives its helium through NASA. In addition to missions launched from U.S. locations (Palestine, Texas; Ft. Sumner, New Mexico), CSBF conducts balloon missions from remote locations including Alaska, Canada, Sweden, and Antarctica.

DOD continues to rely on the buoyancy of helium in blimps it develops for surveillance and reconnaissance. Some examples are the Rapid Aerostat Initial Deployment (RAID) program and the Persistent Threat Detection System (PTDS) program. DOD is also developing a significantly larger version of these devices (JLENS) for permanent installation in the United States as part of a system to sense and defend against cruise missiles. The Army is using more than 25 lighter-than-air devices in Iraq and Afghanistan, where they surveil for security and collect weather data.[4]

Lighter-than-air vehicles are also used for advertising and transportation purposes. Perhaps the best known advertising usage is the Goodyear blimp. Goodyear blimps lose very little helium in normal operations, although the gas does have to be purified about twice a year. As the envelopes age and tend to leak gas via diffusion, the crew might have to supplement the amount of helium in the blimp, sometimes by as much as 10 Mcf of gas per month. The requisite gas is acquired along the tour and added as needed.[5]

During the 1990s there was interest in developing large helium-filled airships for moving cargo in remote areas. One of the better known companies, Cargolifter AG, never went into full operation and was liquidated in 2002. Other companies are supposedly considering luxury passenger travel and high capacity cargo freighters.

Conservation and recycling seem to be options in these markets if the price signals are right. Hydrogen is a potential substitute for lifting provided that safety considerations are met.

High-Energy Laser

Gaseous helium is used in ongoing DOD research in the development of high-energy lasers at the Wright-Patterson, Kirtland, and Eglin air force bases, as well as at the White Sands Missile Range.

[4]Presentation to the committee by Sharon Murphy, Director, Aerospace Energy, Defense Energy Support Center, August 21, 2008.

[5]Available at http://www.goodyearblimp.com/faqs/ faqs_construction. html#helium.

Next-Generation Nuclear Reactors

The concept of a gas-filled nuclear reactor, first discussed in the 1950s, is presently being developed for energy production. Two reactor classes, generically known as high-temperature reactors (HTRs) and very-high-temperature reactors (VHTRs) (including pebble-bed reactors), utilize graphite-moderated cores for energy production and helium as a coolant. In the nuclear reactor application, helium has the distinct advantages of (1) high heat transfer capability, (2) chemical inertness, and (3) not forming isotopes and thus not producing deleterious radiogenic by-products. Such designs are under serious consideration and development in the United States as well as in other nations, including South Africa, the Netherlands, and China. In addition to being potentially significant sources of energy, these reactors will have a critically important secondary use: as highly efficient incinerators for the disposal of surplus weapons-grade plutonium.

According to the 2007 report of the International Panel on Climate Change, the production of electricity by nuclear fuel could be a good option for mitigating greenhouse gases. Presently, approximately 16 percent of energy production worldwide derives from nuclear fission (IPCC, 2007), with production in 2005 of 2,626 TWh of energy using 65,500 tons of uranium. Nuclear reactors are being planned or proposed for China, India, Japan, Korea, Russia, and South Africa. The amount of helium needed for each reactor has been estimated at approximately 1 MMcf, with a loss rate of approximately 0.1 MMcf per year.[6]

While the future helium requirement for VHTR and HTR energy production has not been reliably quantified, helium consumption by this particular U.S. and global sector will increase. No ready substitutes are available, given the high temperatures and heat loads demanded by these facilities. Advanced recycling and recovery efforts might reduce estimated helium loss rates.

Leak Detection

Because of its low viscosity and large diffusion coefficient, helium is an excellent leak detector gas and is widely used as such in science and technology. In one detection method, a vacuum pump is used to pull helium sprayed outside the system through the leak and into an extremely sensitive mass-spectrometer-based helium leak detector. This detection process is the gold standard for any industry that relies on a high vacuum, including the electronics and advanced materials industries, in scientific research, and in the testing and manufacture of large rocket engines.

[6]From correspondence with a representative of Pebble Bed Modular Reactor (Pty.) Ltd., a South Africa-based company that develops high-temperature nuclear reactors.

The use of helium for leak detection has varied widely from year to year, having accounted for approximately 3 to 6 percent of helium consumption in the United States from 1970 to 2006.

There are several approaches to reduce the usage of helium for leak detection. One alternative gas would be hydrogen, whose molecule is only slightly larger than a helium atom but has the disadvantage of flammability. One solution is to mix 4 percent hydrogen with nitrogen to keep it below the hazardous range. However this mixture is much less sensitive than pure hydrogen or helium. Another option with limited applicability is to use closed-loop systems for leak detection. None of these techniques will fully replace helium. For this reason, helium will probably continue to dominate leak detection for the foreseeable future and will have only limited responsiveness to price.

Breathing Mixtures

Several gas combinations containing helium are widely used as breathing mixtures. Although many alternative gas mixtures containing hydrogen or inert gases other than helium have been tried, they are not likely to see wide application or serve as substitutes for mixtures containing helium. The main gases that have been used are Heliox, Trimix, and Heliair, which are mixtures of helium and oxygen, helium with nitrogen and oxygen, and helium and air. Heliox has been used for medical applications since the 1930s to alleviate the symptoms of upper airway obstruction, and its medical use in recent years has expanded. Trimix and Heliair are strictly for nonrecreational use in military, scientific, commercial, and advanced technical diving.

Substitutes also include neon, whose greater density results in less absorption by body tissues than helium or nitrogen. A mixture of 75 percent neon and 25 percent helium has been used, as well. Neon does not seem to have any narcotic effects but is only very slowly released from body tissues, causing long decompression times. Argon is a highly narcotic gas (significantly more so than nitrogen) and because it is dense, it makes breathing difficult on very deep dives. Breathing mixtures containing helium constitute 2 to 3 percent of the use of helium. The growth in this application is not known nor is there any obvious route to helium recovery.

4

Helium Sourcing and Reserves

INTRODUCTION

This chapter discusses in greater detail the history of and trends in helium sources, both in the United States and abroad. The first section focuses on the helium reserves—the natural gas fields that have sufficient concentrations of helium so that helium can be commercially extracted. The second section discusses current and near-term future capacities to produce helium. The final section compares that capacity to the current and anticipated global demand for helium described in Chapter 3, with a focus on the Bureau of Land Management's (BLM's) component of the supply side of the market and some of the possible scenarios that might allow BLM to change its supply strategy for the Federal Helium Reserve in the future.

CURRENT AND PROJECTED SOURCES OF HELIUM

The natural occurrence of helium on Earth is widespread—approximately 5 parts per million of the atmosphere is helium. However, because the cost of removing helium from the air is significantly higher than that of procuring it from alternative sources, it is unlikely that air will be a source of helium in the foreseeable future. Instead, almost all commercially available helium is extracted from a small number of natural gas reservoirs with relatively high concentrations of helium. In the last several years, as natural gas liquefying facilities have come on line, the amount of potentially recoverable helium has increased, since one consequence of liquefying natural gas is to increase the relative concentration of helium and, therefore, the cost effectiveness of extracting it. This section discusses current and projected sources of helium, both in the United States and elsewhere.

Overview

Every year the BLM, acting on behalf of the U.S. Geological Survey (USGS), summarizes global helium resources. Table 4.1 lists estimates for helium reserves and the helium reserve base in 2008. "Reserves" are resources that "could be economically extracted or produced at the time of determination, [but] need not signify that extraction facilities are in place and operative."[1]

For helium resources abroad, the "reserve base" is the "in-place demonstrated resource . . . [that has a] reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics [and] includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic reserves)."[2] For the United States, the reserve base reported in Table 4.1 includes measured (153.2 Bcf) and probable (192.2 Bcf) helium reserves but specifically excludes the possible (213.8 Bcf) and speculative reserves (184.4 Bcf) published in the 2009 USGS report on helium (USGS, 2009). It is important to note that all listed reserves and reserve bases are estimates and with few exceptions have not been certified by any accrediting institution.

For the world, the total estimated reserves of 638 Bcf divided by the current global helium refining rate of approximately 6.2 Bcf per year[3] indicates reserves should last about 100 years. However, if consumption continues to grow at recent rates (4 percent per year), these reserves fall to a less comfortable 40 years. Furthermore, it is important to note that this estimate is valid only if the entire amount of natural gas produced from each reservoir is processed for helium. An improved assessment of the life of a country's reserves would require adjusting for the amount of helium that is bypassing helium-processing plants for that country—that is, gas that is being vented to the atmosphere never to be recovered. To account for such losses would require obtaining, for each field with commercially available helium, information about the amount of natural gas produced from that field over a given period and the helium concentrations in that gas and then comparing the result to the amount of helium actually produced. The ratio of helium extracted to the amount of helium withdrawn, extrapolated to the amount of reserves estimated for the field, would provide an effective reserve for that field. For almost all coun-

[1]USGS, 2009, Appendix B.

[2]Ibid.

[3]Discussed later in this chapter in the section entitled "Refined Helium: Current Capacity and Production."

TABLE 4.1 Estimates of Helium Reserves Worldwide, 2008 (billion cubic feet)

Country	Reserves[a]	Reserve Base[a]
United States	153	350[b]
Algeria	64	300
Australia	NA	6.9[c]
Canada	NA	72
China	—	40
Indonesia	NA	14[c]
Poland	0.9	10
Qatar	360[d]	360
Russia	60	250
Other countries	NA	8.1
Total	638[d]	1,410

NOTE: NA means not applicable, as the country has no refining capacity.

[a]Entries are those from USGS, 2009, unless otherwise specified and are current estimates based on available information. They are not certified by any accrediting institution.

[b]Includes measured and probable reserves rather than measured and indicated, as for other countries.

[c]Conservative estimates based on planned liquid helium plant capacity (see discussion in text) and a 25-year minimum plant productive life.

[d]According to information compiled by the DOE's Energy Information Administration, as discussed in the text.

tries, the aggregate effective reserves for their fields would be substantially less than the reserves shown in Table 4.1. In the one case outside the United States where information was available, this determination decreased the effective reserves of that country by as much as 70 percent.[4] The information necessary to make such estimates is generally not publicly available, but it can be stated that in the United States such losses in reserves—that is, losses due to bypassing—though not negligible, are much less severe than in Qatar.

United States

The United States has reserves of approximately 153 Bcf and a reserve base of 350 Bcf. Table 4.2 details the amount of reserves for all principal fields in the United States currently believed to contain economically accessible concentrations of

[4]The country in question, Qatar, produced approximately 2,200 Bcf of natural gas in 2007, most of it from the North Field (U.S. Energy Information Administration-Qatar, 2009). Based on an estimated helium concentration of 0.04 percent by volume in the North Field (Daly, 2005), 880 MMcf of helium were produced by Qatar during 2007. However, only 250 MMcf of helium are reported to have been refined over that time period (USGS, 2009), indicating that only about 30 percent of the natural gas from the field was processed for helium, which corresponds to a waste factor of 70 percent.

TABLE 4.2 U.S. Helium Proven Reserves, 2007 (billion cubic feet)

Location	Reserves (Bcf)	
Hugoton-Panhandle complex	47	
Hugoton-Panhandle complex (except Bush Dome)	20.5[a]	
BLM helium stored at Bush Dome		23.1[b]
Private storage at Bush Dome		1.1[b]
Native helium		2.3[b]
Riley Ridge Field, Wyoming (ExxonMobil)	49[c]	
Rands Butte, Wyoming (Cimarex Energy)	17[d]	
St John's Field, Arizona (Enhanced Oil Resources Inc.)	14	
Others	26[a]	
Total	153[b]	

[a]By difference.
[b]USGS, 2009.
[c]From analyses of data in NRC, 2000, and State of Wyoming, 2008.
[d]Cimarex, 2008.

helium (USGS, 2009). The two most important U.S. sources of helium are the Mid-continent Hugoton-Panhandle field complex, in Texas, Oklahoma, and Kansas, and ExxonMobil's Riley Ridge Field in southwestern Wyoming. Most production from the Hugoton-Panhandle complex is connected to or could be connected to the Helium Pipeline and the Bush Dome Reservoir, all noted in Figure 4.1.

The sources of the estimated amounts for the fields other than the Hugoton-Panhandle complex are footnoted in Table 4.2. For example, Table 4.2 of the 2000 Report gives the Riley Ridge field helium reserves as 67 Bcf in 1997. The cumulative helium extracted from 1998 to 2006 inclusive is 18 Bcf (State of Wyoming, 2008), resulting in the 49 Bcf reserves reported in Table 4.2.

The Rands Butte resource is a project proposed by Cimarex Energy Co. to recover methane and helium from the Madison formation. Cimarex expects to recover 620 Bcf of methane and 17 Bcf of helium over the life of the project. Acid gases would be injected back into the formation, and no NGLs or sulfur will be produced. The St. John's Dome field, in Arizona, is a project whose primary purpose is to recover CO_2 for enhanced oil recovery (EOR) in the Permian Basin of New Mexico and Texas. The estimated volume of gas in the field is several trillion cubic feet. It contains about 95 percent CO_2, 4.4 percent N_2, and 0.6 percent He, along with minor amounts of CH_4 and argon.[5] The associated helium reserves

[5]Available at http://www.tristonecapital.com/upload/divestiture/41/04/eor_om.pdf?1237509665. Last accessed August 6, 2009.

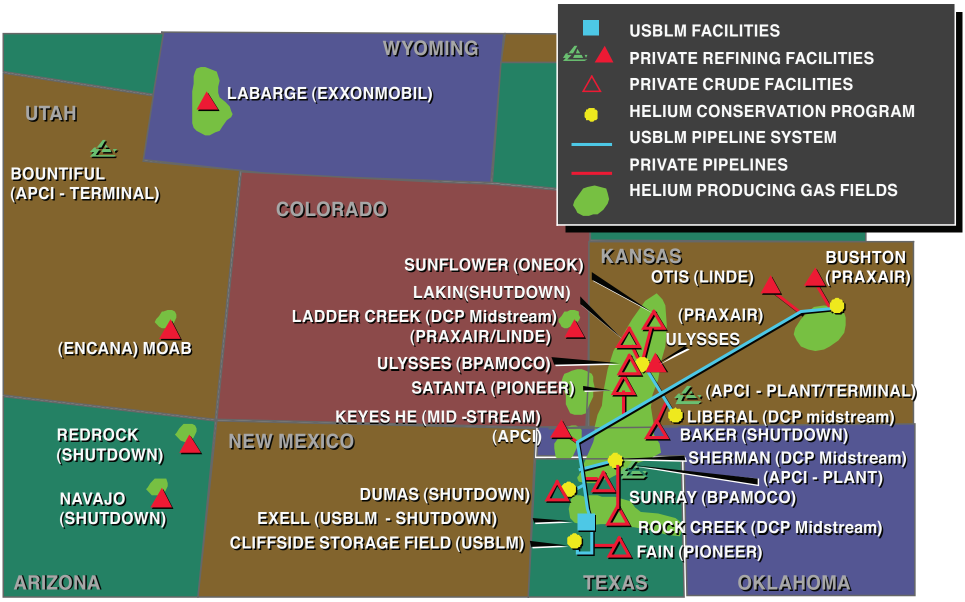

FIGURE 4.1 Map of helium supply sources and major facilities in the United States. SOURCE: Air Products and Chemicals, Inc.

for Phase I of that project are about 14 Bcf. The reserves for the Rands Butte and St. John's projects reported in Table 4.2 will not be proven until their processing plants become operational.

The quantities of reserves in parts of the Hugoton-Panhandle complex are determined by combining information gathered by the USGS and other entities. The 2009 USGS survey estimates that as of December 31, 2006, the combined reserves of the Hugoton-Panhandle complex, the Riley Ridge field, and the Bush Dome Reservoir were 96 Bcf (USGS, 2009). Subtracting the 26.5 Bcf present in the Bush Dome Reservoir and the 49 Bcf estimated to be in Riley Ridge, the net amount of helium remaining in the Hugoton-Panhandle complex is 20.5 Bcf. The "Others" category, with reserves of 26 Bcf, obtained by taking the difference, includes future contributions to reserves from both known and unknown resources.

Dividing the 153 Bcf U.S. reserves in 2008 by the helium refining rate of 4.7 Bcf per year[6] indicates that the U.S. helium reserve lifetime is about 30 years. That is, current U.S. helium reserves would last 30 years if the refining rate continues at 4.7 Bcf per year and no helium bypasses the refining plants. The committee notes

[6]As discussed in the section "Refined Helium: Current Capacity and Production" (see Table 4.3).

that approximately 50 percent of that amount currently is being exported. So, if the exporting of helium were curtailed, then helium reserves in the United States would last almost 56 years at the present domestic rate of consumption of approximately 2.5 Bcf per year.

International

Algeria, Qatar, and Russia have reserve bases comparable to that of the United States. Qatar is unique in that essentially all of its natural gas is in the huge North Field, reported to have proven natural gas reserves of approximately 900 trillion cubic feet (Tcf) at the end of 2008 (U.S. Energy Information Administration-Qatar, 2009). The helium concentration in that field is 0.04 percent by volume, or 360 Bcf of helium. Algeria also has very large natural gas reserves but the helium concentrations are lower than those of Qatar.

Russia has the largest natural gas reserves in the world (U.S. EIA-Russia, 2009), and those reserves include some gas fields that have attractive helium concentrations, particularly in the Russian Far East. In fact, the helium contained in the Kovykta field alone could be as much as 180 Bcf.[7] Although there are large volumes of helium in the natural gas reserves in Kovykta as well as other fields in the former Soviet Union, decisions affecting helium development, such as the location of pipelines and liquefied natural gas (LNG) processing plants to satisfy domestic and external markets, are in various stages of planning and it is not known how much planning is being done to develop helium production facilities alongside the other gas handling and processing facilities.

Australia and Indonesia have natural gas reserves with threshold-mass concentrations of helium comparable to that of countries that already are major exporters of LNG. Australia has a helium plant under construction in Darwin and Indonesia is considering helium as an export product.

REFINED HELIUM: CURRENT CAPACITY AND PRODUCTION

Following from the discussion in the preceding section of possible sources of helium, this section turns to a discussion of the current and near-term-future capacity to separate that helium from the natural gas, refine it, and place it into the supply chain discussed in Chapter 2.

Table 4.3 presents helium capacity and actual production in 2008 for those countries with significant sources of helium and facilities for refining it. For purposes of this table, crude helium capacity (column labeled (a)) is the amount of

[7]Based on private conversations with representatives of Russian Federation natural gas supply companies.

TABLE 4.3 Worldwide Crude and Refined Helium Plant Capacities Compared to Refined Helium Produced, 2008

Country	Capacity (Bcf/yr) Crude Helium (a)	Liquid Helium (b)	Liquid Helium Refined (Bcf/yr) (c)	a/b (%)	Refining Plant Usage c/b (%)
United States					
BLM System					
Plants connected	1.55	4.05	3.34	38	82[a]
Bush Dome Reservoir	2.10	0.00	0.00	NA	NA
Subtotal BLM system	3.65	4.05	3.34	90	82
Nonconnected plants	1.68	2.04	1.40	82	69
Subtotal U.S.	5.33	6.09	4.74	88	78
Outside the United States					
Algeria	0.92	0.92	0.80	100	87
Poland	0.09	0.14	0.09	64	64
Qatar	0.60	0.60	0.45	100	75
Russia	0.25	0.22	0.23	114	105
Subtotal non-U.S.	1.86	1.88	1.56	99	83
World total	7.19	7.97	6.30	90	79

NOTE: See text for description of crude helium and liquid helium capacity definitions. NA, not applicable.
[a]The total crude capacity supplying the refining plants associated with the BLM system is 1.55 + 2.10 = 3.65 Bcf/yr.

crude helium that can be delivered for a given reservoir or collection of reservoirs, as limited by the delivery infrastructure and the upgrading stages of the refining processes. Liquid helium refining capacity (column labeled (b)) is equal to 95 percent of the maximum rated output, or nameplate capacities, of the plants considered in the line item. Crude capacity is vulnerable to reservoir depletion and the associated natural reduction in the rate at which gases can be extracted from the reservoir.

United States

To properly account for the various flows of crude to marketable refined high-purity helium products, the U.S. helium supply is considered in three groupings:

- Plants connected to the Helium Pipeline and the Bush Dome Reservoir (the BLM system) that also have their own source of crude helium,
- The BLM crude reserve, stored in the Bush Dome Reservoir, and
- Plants not connected to the BLM system.

The total U.S. refining capacity substantially exceeds the amounts of helium that have been refined every year in recent years. In 2008, while refining capacity was 6.09 Bcf, the crude capacity feeding the refiners annual output was only 5.33 Bcf, or 88 percent of refining capacity. The amount of refined helium produced in the United States in 2008 was 4.74 Bcf, or 88 percent of crude capacity and 78 percent of refining capacity. Also note that 2008 crude capacity from the natural gas fields surrounding the Helium Pipeline was only 38 percent of the related refining capacity. The 2008 worldwide crude capacity was 90 percent of refining capacity and refined production was only 79 percent of refining capacity. Note that if the world's crude capacity of 7.19 Bcf is reduced by the 2.1 Bcf of crude helium supplied from the Federal Helium Reserve, the remaining net crude capacity is 72 percent of the refining capacity.

U.S. Helium Facilities Connected to the BLM System

As discussed in Chapter 2, the natural gas producers for most facilities in the United States generate crude helium in the process of their refining of the natural gas, with the crude helium considered a relatively minor by-product of the much larger natural gas production. Crude helium produced from the Hugoton-Panhandle complex, located in the midcontinental region of the United States, is sold to one of four refined-helium producers with refining facilities connected to the Helium Pipeline.[8] Typically, the refining facilities are near the natural gas processing facilities and the crude helium is delivered pursuant to long-term take-or-pay contracts whereby the buyer takes any crude helium produced or pays for the amount which is not taken. The crude helium can generally be delivered to a helium refining facility directly or to the Helium Pipeline. Crude helium not needed by current demand from the refiner can be stored for future refining in the Helium Pipeline or the Bush Dome Reservoir.

One of the principal issues facing facilities connected to the Helium Pipeline is the lack of feedstock due to the maturity of the gas fields. This has made it difficult to maintain the delivery of helium to the refining facilities at sufficiently high rates without additional and sometimes substantial capital investments.[9] Since the reserves remaining in these fields are relatively low, these investments are often not very attractive.

[8]As this report is being written, those four refined-helium producers are Air Products, Linde, Praxair, and Keyes Helium, which own a total of six helium refining plants connected to the Helium Pipeline.

[9]Typically, modifying the delivery infrastructure could entail work on any or all of the following: vacuum pumps, compressors, workovers of existing wells, additional conventional or deviated wells, hydraulic fractures, and redesign of the gas gathering system.

In the committee's judgment, the amount of available helium is decreasing to the point that most if not all U.S. helium refining facilities connected to the Helium Pipeline will cease to operate in less than 10 years. The collective cost of replacing these refining plants, which could still be operated for many years, is close to $1 billon. One avenue that could be pursued to avoid shutting these facilities down would be to explore the possibility of connecting other fields to the Helium Pipeline to increase the feedstock and keep the refining facilities operating.

Another avenue would be to reconsider the current policy requiring the selldown of the helium in the Bush Dome Reservoir and, instead, to restrict that helium's use to limited purposes. This alternative would result in the retiring of a significant portion of the refining capacity connected to the Helium Pipeline. Inasmuch as the committee believes that the Bush Dome Reservoir is likely to contain significant crude helium reserves well beyond 2015, this likely imbalance between crude helium supplies and refining capacity in the Federal Helium Reserve and the associated Hugoton field requires attention. Moreover, the long lead times associated with any reconfiguration of the helium refining infrastructure connected to the Helium Pipeline means that plans for this eventuality must be developed very soon.

U.S. Helium Facilities Not Connected to the BLM System

ExxonMobil's Shute Creek gas processing facility in Wyoming handles approximately 700 MMcf of natural gas per day from its Riley Ridge gas field. Gas recovered from that field contains approximately 66.5 percent CO_2, 20.5 percent methane, 7.4 percent nitrogen, 5.0 percent hydrogen sulfide, and 0.6 percent helium. The processing facility produces methane gas, CO_2 (for EOR), and helium. The hydrogen sulfide recovered as a by-product is injected back into the reservoir. In 2008 the facility operated at peak capacity, processing 242.7 Bcf of natural gas and producing approximately 1.5 Bcf of refined helium. In calendar year 2008, Shute Creek provided more refined helium than any other facility in the world.

As mentioned in the earlier discussion on helium sources, Cimarex Energy Co., the operator of Riley Ridge Unit 15, has proposed the Rands Butte project to recover methane and helium from the Madison formation. The initial planned capacity is 36.5 Bcf of field gas per year, which would double if so warranted by the gas rates from the field. Acid gases would be reinjected into the formation, and no NGLs or sulfur would be produced. The plant is forecast to come on stream in late 2012, later than originally planned.

The St. John's Dome field project, in Arizona, is being developed primarily to recover CO_2 for EOR in the Permian Basin or in California. The estimated volume of gas in the field is as much as 15 Tcf, with a composition estimated to average 95 percent CO_2, 4.4 percent nitrogen, and 0.6 percent helium, along with minor amounts of methane and argon. The 20-year production outlook estimates the amount of helium that can be recovered may be as much as about 24 Bcf.[10] The project is still under development and the main hurdles include the development of the CO_2 side of the project together with the costly pipeline required to connect the CO_2 recovery facilities to the oil fields' EOR systems.

The refining facilities at Moab, Ladder Creek, and Shiprock are relatively small, having contributed only a small fraction to domestic refined helium production in 2008. Both Moab and Ladder Creek suffer from a shortage of natural gas input to process.

BLM Crude Helium Reserve

The final source of crude for U.S. refined helium is the Bush Dome Reservoir itself. BLM is the only entity with an upgrading plant for supplying crude helium that is not integrated with the final refining stage to make high purity helium. Beginning in 2003,[11] when sales pursuant to the 1996 Act began in earnest, the Federal Helium Reserve became a critical source of crude helium and now provides a significant share of the refined helium consumed in the United States and approximately one-third of the amount consumed worldwide.[12] In fact the Federal Helium Reserve has become the source of first and last resort for refiners on the Helium Pipeline. Chapter 5 discusses sales of crude helium from the Federal Helium Reserve in detail.

Non-U.S. Helium Supply

Outside the United States, the refining capacity of companies producing refined helium in 2008 was 1.88 Bcf, but only 1.56 Bcf of helium was actually refined. The main reason for the difference is mechanical difficulties experienced during start-up of the plants in Algeria and Qatar. Low gas delivery rates from low-pressure mature fields in Russia and Poland were also important. Algeria produced approximately 0.8 Bcf of helium in 2008. Smaller amounts of helium were produced in Russia, Qatar, and Poland.

In both Algeria and Qatar the helium is recovered from the liquefaction of natural gas, where the helium is concentrated in the gases remaining in the tail-

[10]Based on a resource evaluation report issued by W.M. Cobb and Associates of Dallas, Texas, an independent firm of professional engineers in 2008, as discussed in EOR, 2009.

[11]The prepublication version of this report referenced the year in which sales began in earnest as 2005; the correct year is 2003.

[12]According to the most recent data collected by BLM, in 2008 approximately 6 Bcf of helium was consumed worldwide, with 2.3 Bcf of that consumed in the United States. BLM provided 1.9 Bcf of the helium consumed that year. See USGS, 2009.

gases of the liquefaction process, which are then fed to helium purification and liquefaction facilities. These processes are totally integrated. If the crude helium off the liquified natural gas (LNG) tail-gases is not used, then it is vented. Both Algeria and Qatar have very large and established natural gas businesses and LNG operations that will provide the basis for significant expansion of their helium businesses in the years to come. Both are now planning that expansion.

FUTURE HELIUM CAPACITY AND SUPPLY VERSUS HELIUM DEMAND

This final section of Chapter 4 combines the forecast demand discussed in Chapter 3 and the estimated capacity being developed to meet that demand through 2020. It provides a framework for assessing the role that the Federal Helium Reserve could play for different helium capacity scenarios.

Figure 3.3 in Chapter 3 contains forecasts of U.S. and foreign demand for refined helium through 2020. Figure 4.2 shows actual crude helium capacity from 2005 through 2008 and forecasts for that capacity from 2009 to 2020. Other than a facility in Australia that is to produce modest amounts of helium beginning in 2009, no significant new crude or refined capacities will be added before 2012. However, the capacity of many U.S. and foreign plants that recover crude helium and then refine it will continue to be improved. These improvements will help to offset the

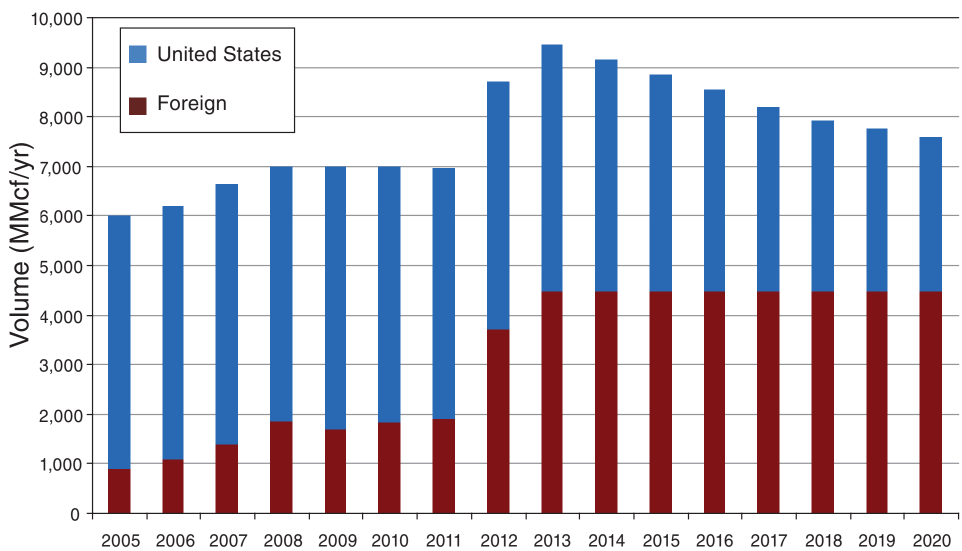

FIGURE 4.2 Actual (2005 to 2008) and estimated (2009 to 2020) crude capacity in the United States (blue) and in other countries (red).

reduction in field crude production from the Hugoton-Panhandle complex, which will decline as deposits are depleted. It is the committee's judgment that this decline will begin in 2010 and accelerate to 10 percent per year by 2012.

Starting in 2012, several new plants for recovering crude helium and refining it, now in construction or in the planning stage, will begin operations. All such plants are likely to be in operation by 2015, are natural gas-based, and integrate refining capacity with crude recovery and processing capacity to produce refined liquid helium:

- Linde in Darwin, Australia, projected to come on stream in 2009;
- The Cimarex project in Wyoming, a venture of Cimarex Energy Co., Taiyo Nippon Sanso (TNSC), and Air Products, forecast to come on stream in 2012;
- One or more of the large refining facilities to come on stream in Qatar by 2013; and
- One or more of the large refining facilities to come on stream at Arzew, Algeria, by 2013.

While there are other projects under consideration, it is likely that the only additional capacity by 2015 will be the above. After 2015, significant new refined helium capacity in the United States, Canada, Indonesia, and the Russian Far East is under consideration. Except for the project in St. John's Dome field, in Arizona, all of the projects being planned are based on natural gas and/or LNG facilities.

Figure 4.3 shows the split in crude capacities by sources in the United States and foreign countries for the critical years of 2005 (actual history), 2008 (most recent documented), 2015 (when significant increases in foreign crude/refined capacity have been fully developed), and 2020 (the end of this study's forecast period). The changes in capacities in Figure 4.3 are mainly attributable to the following:

- The significant increase in foreign capacity from plants with integrated crude and refined capacities,
- The very modest increase in U.S. crude and refined capacity from plants not connected to the Helium Pipeline,
- The notable reduction in the amount of helium produced in those fields connected to the Helium Pipeline, and
- The modest reduction in crude from the Bush Dome Reservoir because of reduced reservoir withdrawal rates.

Figure 4.4 shows the development of crude helium capacity by region. "Other" includes Australia, Canada, and Indonesia. Australia is under construction and is therefore included in the forecast, but Canada and Indonesia are still considered speculative and no new capacity is forecasted for them.

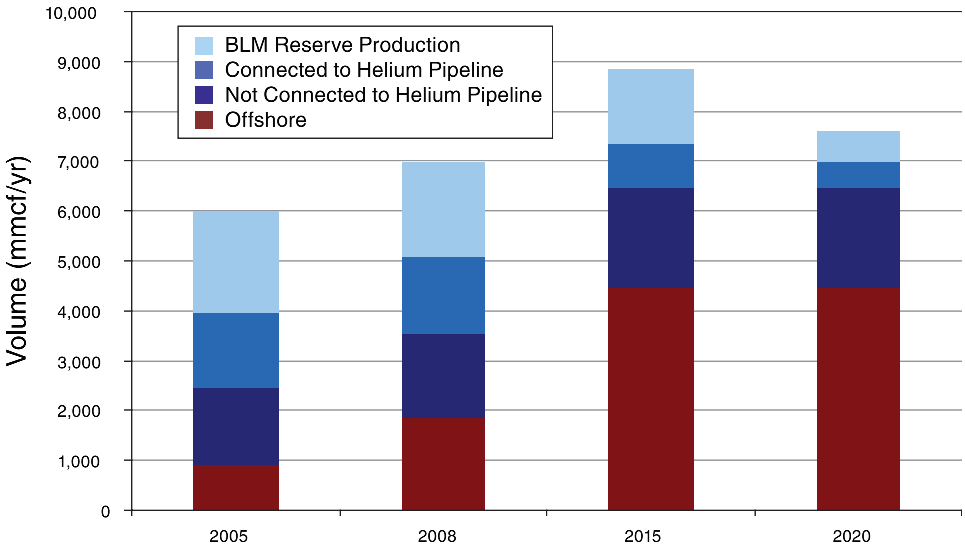

FIGURE 4.3 Actual (2005 and 2008) and estimated (2015 and 2020) crude helium capacities by crude helium source.

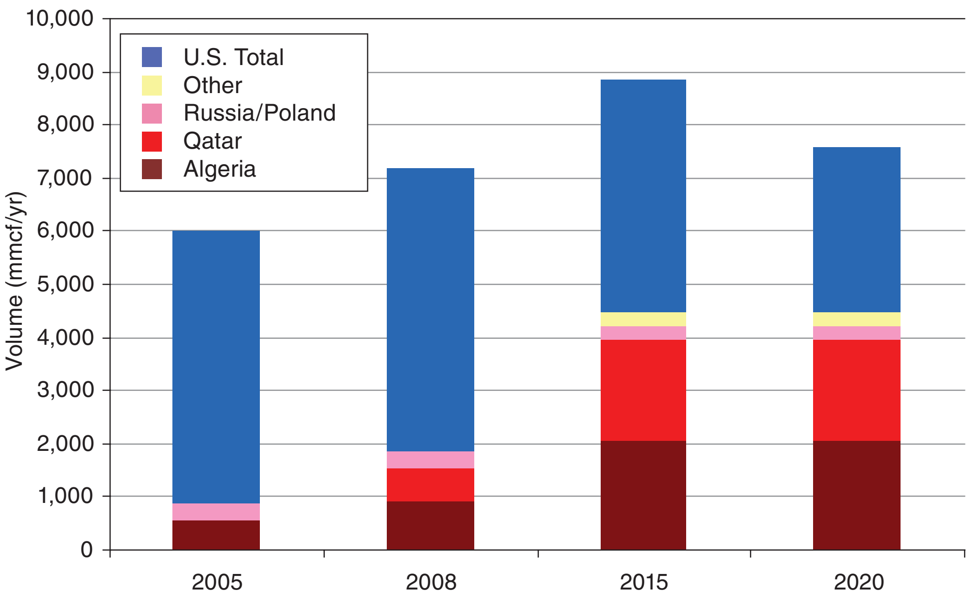

FIGURE 4.4 Actual (2005 and 2008) and estimated (2015 and 2020) crude helium capacities by crude source country.

Figure 4.4 illustrates how the distribution of crude capacities by country will change significantly over the next decade. The very large share of crude and refined capacity that existed in the United States in 2005 permitted the United States to serve all of its own needs and much of the need of the rest of the world. The abundance of U.S. helium at reasonable costs led to the development of many of the largest and most critical uses of helium (see Chapter 3).

As discussed earlier, significant increases in foreign capacity are expected to develop by 2015, at which time U.S. capacity will begin to decline owing to accelerating net depletion of the U.S. midcontinental crude reserves and the associated decline in extraction capacity. By 2020, U.S. crude capacity will have severely declined, and that decline is expected to continue unless more U.S. helium sources are developed.

Figure 4.5 shows demand and crude capacity from 2005 through 2008 for both U.S. and foreign markets and anticipated demand and crude capacity from 2009 to 2020. From 2005 until 2012, the United States has been and will continue to be a net exporter of helium, supplying the difference between foreign demand and foreign capacity. In the years 2005 through 2008, the difference between foreign crude capacity and demand has been approximately 2.0 Bcf, roughly equal to the amount of helium withdrawn annually from the Bush Dome Reservoir during

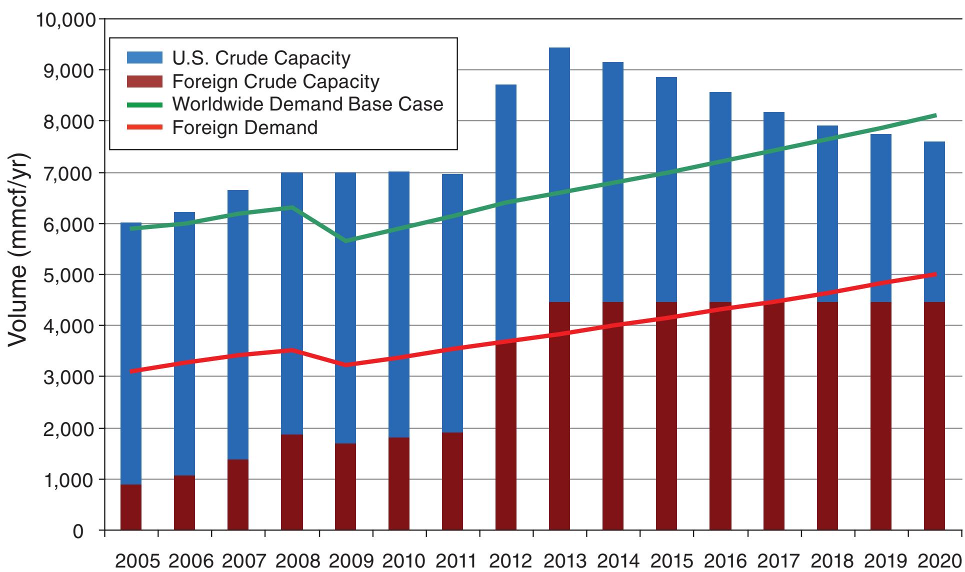

FIGURE 4.5 Actual (2005-2008) and estimated (2009-2020) demand and capacity for crude helium in the United States and other countries.

those years. It is expected that under the current drawdown schedule for the Bush Dome Reservoir and with the depletion of several of the domestic helium sources, the United States will become a net importer of helium in the near future.

Several other points are important as well. The slight surplus in refining capacity from 2005 to 2007 did not allow supply to keep up with actual demand, as a surplus in capacity of at least 10 percent is normally needed to accommodate seasonal and month-to-month fluctuations in demand. During the last half of 2008, U.S. and worldwide demand began to slip against a relatively flat supply, so that there was a surplus of at least 10 percent of demand, permitting a much more reliable supply.

By 2012, after planned refining facilities come online, foreign capacity is expected to be able to supply virtually all of foreign demand, at least when based on annualized capacity. Should world demand continue to grow as forecast beyond 2016, world capacity would have to increase faster than current expectations. If it fails to do so, the price of helium will increase, which would probably constrain demand, jeopardizing the world's helium demand/supply balance as in 2005 through 2007. This is where additional capacity in Algeria, Qatar, and the Russian Far East could come into play.

AN ALTERNATIVE ROLE FOR THE FEDERAL HELIUM RESERVE

As shown in Figure 4.5, reductions in world demand for the next several years as a result of the economic downturn and the start-up of helium extraction and refining facilities thereafter will result in substantial excesses in helium production capacity through approximately 2015 (Case A). This would be an opportunity for the Federal Helium Reserve to depart from its current role as the source of first resort for crude helium and take on a new role as a source of last resort, thereby allowing BLM to provide helium for domestic use for a significantly longer time than is currently projected.

As a source of last resort, helium would be drawn from the Federal Helium Reserve only to make up for shortfalls in all other supply sources (Figure 4.6, blue). Note that in this scenario, called Case B, very little federally owned crude helium would be required to meet world demand from 2012 to 2017.

As shown in Figure 4.7, the net effect of reducing BLM withdrawal rates under this alternative model would be to greatly increase the amount of federally owned helium at critical points in the supply and demand forecasts to 2020, allowing BLM to better provide for the long-term helium needs of the United States.

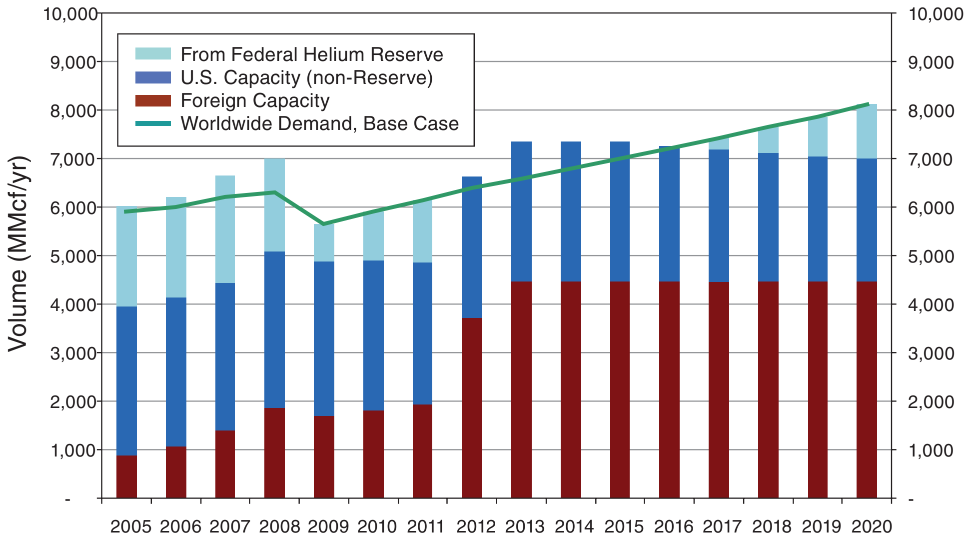

FIGURE 4.6 The alternative usage of federally owned crude helium as a source of last resort. The colored bars show the helium capacity of the various potential sources of helium; the green line shows actual (2005-2008) and estimated (2009-2020) worldwide demand.

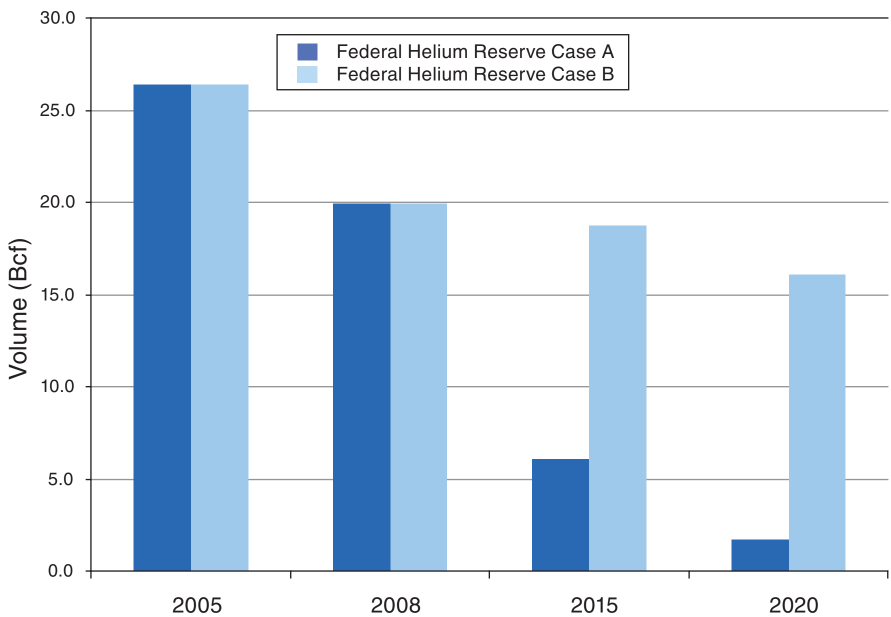

FIGURE 4.7 Amount of crude helium in the Bush Dome Reservoir under the current scenario (Case A), where 2.1 Bcf of helium is withdrawn from the reservoir each year, compared with the amount under the alternative scenario (Case B), in which the Bush Dome Reservoir is treated as a source of last resort, drawn on only to meet the needs of helium users not satisfied by other sources.

5

Operation of the Federal Helium Reserve Facilities

INTRODUCTION AND HISTORY

The Federal Helium Reserve[1] has been an important component of the global helium supply chain for as long as the helium market has existed and, just as importantly, served over that same time period as a national resource, created and maintained to meet our nation's critical needs. This chapter discusses the Reserve, first summarizing its history and then (in response to a portion of the statement of task) evaluating how effectively the Reserve has served as a flywheel, enabling more efficient use of the Bush Dome Reservoir and the refineries connected to it via the Helium Pipeline. The chapter continues by describing recent efforts to better characterize the nature and capabilities of the Bush Dome Reservoir and gives supplemental recommendations to improve those capabilities. It concludes by evaluating the implications of the 1996 Act's mandate for the management of the Reserve—that is, that the federally owned helium on deposit in the Federal Helium Reserve be sold on a straight-line basis—and proposes alternative approaches for extracting the crude helium in the Reserve that might better meet the nation's needs.

Facilities

The history of helium as a valuable national resource began in 1903, in Dexter, Kansas, when a natural gas field produced gases that would not burn. It was discov-

[1]The components of the Reserve are identified and defined in Box 1.1 in Chapter 1.

ered that the gas contained primarily nitrogen but also almost 2 percent helium. Further exploration revealed that a number of the fields beneath the Great Plains contained significant percentages of helium that could be extracted relatively easily. It was quickly realized that helium's buoyancy and relative inertness, particularly when compared to the intensely flammable alternative, hydrogen, made it an ideal lifting gas for military airships. Consequently, during the 1910s the United States, through its Bureau of Mines (BOM), contracted for the construction of three small experimental helium production facilities in Texas.

Although World War I ended before helium from these facilities could be used in the war effort, the U.S. Navy immediately began a program to develop rigid airships and by 1921 had built a full-scale helium production plant near Forth Worth, Texas, linked by pipeline to the Petrolia gas field, an early source of helium-rich natural gas. Several years later, Congress enacted the Helium Act of 1925 (1925 Act), formalizing the importance of helium and transferring operation of the Fort Worth production facility from the Navy to BOM. The 1925 Act declared helium a critical war material, tightly controlled its production, and curtailed exports.

Several more plants went into production shortly thereafter, including a unit near Amarillo, Texas, fed with natural gas from the nearby Cliffside field. World War II saw dramatic increases in helium production to support lighter-than-air naval reconnaissance aircraft—dirigibles flown by the Navy to locate and protect its convoys from enemy submarines and warships. By the end of the war, five helium plants were operating at full capacity.

In the 1950s and 1960s, the cold war initiated yet another major expansion of the federal helium program, with helium then being used mainly for rocket development and in scientific research. In 1960, as part of those efforts, Congress amended the 1925 Act to accomplish two things. First, it gave natural gas producers incentives to separate helium from natural gas and sell it to the federal government. Second, it established that a partially depleted dome reservoir in the Cliffside gas field (referred to in this report as the "Bush Dome Reservoir") would serve as a helium depository to build up a strategic reserve of helium. The incentives caused several private oil and gas producers to enter long-term helium purchase agreements with BOM and to build five helium extraction plants in the most promising natural gas fields in Kansas, Texas, Colorado, and Oklahoma. The existing pipeline for helium was significantly extended to link those plants, running from the Bush Dome Reservoir to Bushton, Kansas, over 400 miles away (as described in Box 1.1, its current manifestation is referred to in this report as the "Helium Pipeline").

By 1973, it had become apparent that demand for helium was much less than the amount that private parties and the remaining government facilities were supplying. At that time, BOM had accumulated 35 Bcf[2] of crude helium in storage (see

[2]The units used in this report for volumes of helium are listed in footnote 4 of Chapter 1.

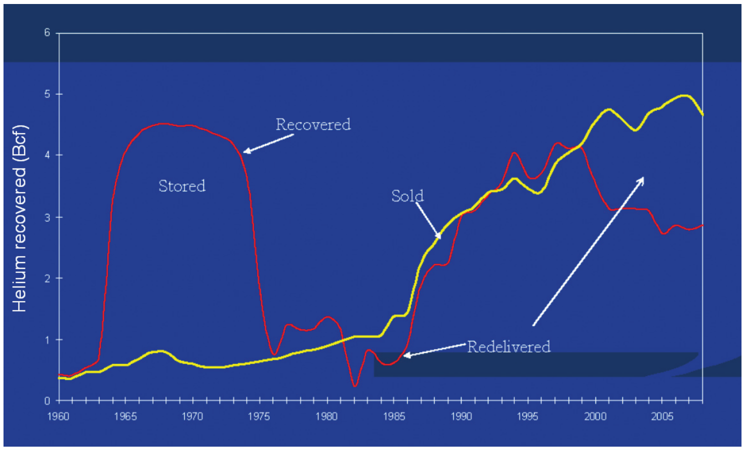

FIGURE 5.1 Crude helium recovered and removed from storage in the Bush Dome Reservoir, 1960-2008. A positive difference between the amount of helium recovered and sold in a given year constitutes an increase (by the amount of the difference) in the amount of helium stored in the Bush Dome Reservoir; a net negative difference constitutes a decrease (by the amount of the difference) in the amount of stored helium. SOURCE: U.S. Department of the Interior's BLM.

Figure 5.1), plus a large and growing debt to the Treasury. That amount far exceeded the approximately 650 MMcf of crude helium being used each year.[3] Given those circumstances, the federal government cancelled the long-term contracts with private suppliers, resulting in litigation that lasted for several years. As shown in Figure 5.1, from that time until the mid-1990s the amounts of helium placed into storage at the Bush Dome Reservoir roughly equaled the amounts withdrawn.

The 1996 Privatization Act

In 1996, Congress sought to resolve outstanding issues regarding the federal government's role with respect to helium through the Helium Privatization Act of 1996 (P.L. 104-273). The 1996 Act, as it is known, has four principal components:

- It directs the Secretary of the Interior ("Secretary")[4] to close all government-owned facilities for refining helium and to terminate the marketing of refined helium.

[3]Bureau of Mines, 1973.

[4]Shortly before enactment of the 1996 Act, Congress closed BOM. In that legislation, BOM's responsibilities with respect to the federal helium program were transferred to the Bureau of Land Management (BLM), which also operates under the Department of the Interior. Available at http://www.doi.gov/pfm/par/acct1995/ar1995bom.pdf.

- With the shutting down of the federal government's helium refining facilities under the 1996 Act, the in-kind program was initiated[5] and requires federal agencies to indirectly purchase helium from BLM. To do so, these users are to purchase refined helium from private firms, which are in turn under contract to purchase equivalent amounts of crude helium from the BLM.
- BLM is allowed to continue to provide helium storage, transportation, and withdrawal services to any person, as long as it recovers the full costs of those services from those persons.
- Finally, BLM is directed to sell all but 600 MMcf of the crude helium then in storage in the Bush Dome Reservoir under the following terms and conditions:
  —The sales are to be conducted so as to minimize market disruption.
  —The selling prices must be sufficient to cover the Reserve's operating costs and to produce a total amount, adjusted for inflation, sufficient to reimburse the federal government in full plus accrued interest for the amounts it had expended to purchase the stored helium.
  —The sales are to be conducted on a straight-line basis and completed by January 1, 2015.

Post-1996 Activities by BLM

In accordance with the 1996 Act, BLM sold its helium refining facilities but continues to manage the rest of the Federal Helium Reserve. In 2003 it began to sell off federally owned crude helium in accordance with the 1996 Act and continues to conduct sales every quarter.

To provide a more reliable flow of crude helium to the refineries linked to the Bush Dome Reservoir, BLM worked with the owners of the refineries to install a crude helium enrichment unit (CHEU) and related compression facilities (Figure 5.2). The CHEU was financed (at roughly $26 million) and currently is managed by the Cliffside Refiners Limited Partnership (CRLP), a partnership set up by the four companies then operating the refineries connected to the Helium Pipeline. Briefings from CRLP member firms to the committee had suggested that CRLP recently assumed increased responsibility for monitoring and managing the flow of crude helium from the reservoir to members' refineries.

[5]The prepublication version of this report inaccurately characterized the 1996 Act as modifying rather than initiating the in-kind program. The 1996 Act initiated the in-kind program by replacing a similar program through which federal agencies directly purchased helium from BLM with the "in-kind" program through which federal agencies indirectly purchased helium from BLM. As explained in the text, the need for the indirect sales structure of the in-kind program arose from provisions in the 1996 Act that required BLM to shut down its helium refining facilities and to cease selling refined helium.

FIGURE 5.2. Crude helium enrichment unit installed to provide a more reliable flow of crude helium to refineries. SOURCE: U.S. Department of the Interior's BLM.

The terms of the cooperative agreement between CRLP and BLM were criticized in a 2008 report by the Interior Department's Inspector General (Interior IG). In addition to responding to these criticisms from the Interior IG, the CRLP may need to consider further investments in facilities that can enhance long-term recovery and reliability of access to the remaining Bush Dome Reservoir crude helium. Since these facilities will take years to plan, design, and build, their feasibility and financing are linked directly to the management of the Bush Dome over the next 10-15 years, well beyond the 2015 cessation of Federal Helium Reserve operations stipulated in the 1996 Act.

BLM'S OPERATION OF THE HELIUM RESERVE

The preceding section laid out the history of the federal government's efforts to develop and sustain a helium program to meet the nation's needs and the legislative mandates for the current activities of BLM. The rest of this chapter examines the current operations of the Federal Helium Reserve, focusing on three components that resonate with the issues being addressed in this report.

The first component is the procedures by which federally owned crude helium is being sold by BLM, pursuant to both the in-kind program and the sell-off provisions of the 1996 Act. In the judgment of the committee, BLM's management of crude helium sales under the authority granted to it by the 1996 Act has had significant effects on overall "market" pricing of crude helium: It has accelerated the exhaustion of the Bush Dome Reservoir and discouraged the conservation of refined helium by users. At the same time, however, a new approach to management of the in-kind program authorized by the 1996 Act could enable BLM to take steps that would partially mitigate both the rising prices and the periodic shortages experienced by some of the scientific users of helium in 2006-2008.

The second component is the use of the Federal Helium Reserve system as a flywheel, whereby crude helium extracted during periods of low demand is stored and then retrieved when market conditions improve. The committee's charge directed it to assess the benefits of BLM's operation of the Bush Dome Reservoir as a flywheel, and the subsection "Efficiency and Conservation Benefits of the Flywheel," later in this chapter, discusses this issue.

The final component is management of the Reserve, especially the Bush Dome Reservoir. Because BLM is charged with managing the large crude helium reserves in the reservoir for the benefit of current and future taxpayers, the committee includes in its discussion of BLM's operation of the Federal Helium Reserve some consideration of the complex issues in reservoir management and investment in reservoir facilities that BLM will confront very soon. It appears highly desirable to the committee that BLM's management of the Bush Dome Reservoir, like its management of other aspects of the Reserve, should adopt a longer-term perspective that extends well beyond the 2015 date by which the 1996 Act mandates sell-off of substantially all of the federally owned crude helium stored in the Bush Dome Reservoir.

BLM Sales of Crude Helium

BLM regularly sells federally owned crude helium under the in-kind program and in accordance with the 1996 Act's directive that it sell substantially all of the crude helium in the Bush Dome Reservoir. As discussed in Chapter 4, the amount of helium sold by BLM makes up a significant fraction of the world supply for a given year. This section describes these programs in more detail and discusses the pricing of these sales and how the pricing impacts other aspects of the helium market.

In-Kind Program of Crude Helium Distribution

The in-kind program is a legislatively prescribed procedure that federal agencies must follow to obtain helium. Before enactment of the 1996 Act, all federal agencies were required to meet any major helium requirement[6] by purchasing helium directly from BLM's predecessor, BOM. With the shutting down of the federal government's helium-refining facilities under the 1996 Act, the in-kind program was initiated and requires federal agencies to meet their major helium requirements by buying, "to the extent that supplies are readily available," refined helium from an authorized federal helium supplier that is under contract to purchase an equivalent amount of crude helium from BLM.[7]

BLM has promulgated regulations governing such sales (43 CFR Part 3195). These regulations cover not only major helium purchases by federal agencies but also purchases by any private contractor or subcontractor that uses a large amount of helium in performing a federal contract. Pursuant to these regulations, in the event of shortages in helium supplies, authorized federal helium suppliers must give federal agencies and their contractors priority over nongovernment users.

Once an entity determines that it must participate in the in-kind program, it obtains a list of authorized suppliers from BLM and then arranges to purchase helium from one of them. The supplier then must purchase an equivalent amount of crude helium from BLM. The price is negotiated between the buyer and supplier and is intended to be on a cost-plus basis, whereby the price paid by the buyer includes the costs of crude helium charged by BLM plus estimated costs of refining and delivering that helium and a reasonable profit for the seller. Table 5.1 shows recent federal agency and contractor use of the in-kind helium program.

At the time this report was being written, most of the small academic research programs that use helium did not participate in the in-kind program even though they are funded through federal grants. BLM reported to the committee that it distinguishes between parties that are under contract to a federal agency and parties that obtain funding through grants from federal agencies. The first group falls within the scope of the in-kind program; the second does not. Further, the amount

[6]The regulations promulgated by BLM define "a major helium requirement" to be more than 200 Mcf of gaseous helium or more than 7,510 liters of liquid helium at a helium-use location per year (43 CFR Part 3195.11).

[7]"The Department of Defense, the Atomic Energy Commission, and other agencies of the federal government, to the extent that supplies are readily available, shall purchase all major requirements of helium from persons who have entered into enforceable contracts to purchase an equivalent amount of crude helium from the Secretary." (50 U.S.C. Section 167d(a)).

TABLE 5.1 In-Kind Sales by BLM to Federal Agencies and Contractors, 2005-2008 (thousand cubic feet)

Purchasing Agency	2005	2006	2007	2008
National Aeronautics and Space Administration	156,478	111,049	118,961	118,917
Navy	6,206	6,534	11,607	9,928
Army	125	14	19	3
Air Force	16,659	17,742	16,537	12,245
DOE	31,327	25,273	22,244	16,723
Other federal agencies	25,351	32,160	33,762	36,897
Total	236,146	192,772	203,130	194,713

SOURCE: Bureau of Land Management, 2005, 2006, 2007, 2008.

of helium used by many of these parties is not enough to qualify as a "major helium requirement."[8]

In addition to the sales provisions mandated by 50 U.S.C. Section 167d(a), the 1996 Act gives BLM discretionary authority to sell crude helium for "federal, medical, scientific, and commercial uses in such quantities and under such terms and conditions as [the Secretary] determines" (50 U.S.C. Section 167d(b)). No regulations have been adopted that delineate BLM's authority to sell helium pursuant to these provisions, and according to conversations with a representative of BLM, no sales currently are taking place under subsection 167d(b). However, to the extent that the statutory language for the mandatory program under subsection 167d(a) is ambiguous, it appears the language of subsection 167d(b) provides BLM sufficient leeway to fashion a program that could mitigate some of the negative consequences for academic helium users of the rising prices and periodic shortages encountered in the past.[9]

[8]The language of the regulation does not appear to permit these small researchers to participate in the in-kind program, both because they use only small amounts of helium and because they are not contractors with the federal agencies but rather operate under grants. At the committee's third meeting, BLM representatives said that small researchers are not permitted to participate in the in-kind program for these reasons. However, as this report was being finalized, BLM representatives indicated that they now believe such researchers are permitted to participate in the in-kind program. Clarification of this point in the language of the regulations would be beneficial in resolving this issue.

[9]The committee also heard from a representative of the Defense Energy Support Center (DESC), which provides for the energy needs of the Department of Defense. Helium is among the materials provided to the armed services under this program, and the representative indicated that it has provided helium to some research programs, both defense- and non-defense-related, under separate authority. Presentation by Sharon L. Murphy, Director, Aerospace Energy, DESC, August 21, 2008.

Sell-Down of Crude Helium Pursuant to 1996 Act

The 1996 Act required BLM to begin to sell substantially all federally owned helium in the Bush Dome Reservoir and Helium Pipeline no later than January 1, 2005. The sales, often referred to in the helium industry as open-market sales,[10] are to take place on a straight-line basis between the starting date and 2015 but must be carried out with minimal market disruption. The statute does not say which of the two potentially conflicting provisions takes precedence. The minimum selling price for all helium sales, in both the in-kind and the sell-off programs, is set by the 1996 Act. BLM's practice has been to use the minimum selling prices defined by the 1996 Act as the actual prices at which it sells crude helium.

BLM holds each open market sale in two steps: an allocated sale and a non-allocated sale. The allocated sale generally accounts for 90-96 percent of the total offering and can be bid on only by owners of the crude helium refining facilities connected to the Helium Pipeline in 2000. Bids are for volume desired. Each refiner has a percentage allocation determined by its share of the total capacity of plants connected to the Helium Pipeline in that year. If one or more refiners request less than their allocated share, refiners that requested more than their share will be allowed to purchase the excess volume. If multiple refiners have requested more than their share, the excess volume is sold based on the proportionate refining capacities of those refiners. Additional proration stages ensue until all requests are filled or no more allocated-sale helium is available. Any volume of allocated-sale helium not sold is offered in the nonallocated sale. Any refiner's request not filled in the allocated sale will be carried over to the nonallocated sale.

The amount available for the nonallocated sale initially is divided into equal shares, based upon the number of bidders. Those who bid for an amount of helium equal to or less than this share amount receive the amount of helium for which they bid. If one or more bidders bid for more than the share amount, then the helium remaining will be allocated equally among remaining bidders, who will then receive their bid or their allocation, whichever is less. The process will continue to additional proration rounds, if necessary.

Table 5.2 shows the results of open-market sales from March 2003 to the fourth quarter of FY 2008 (July-September). Of the 15,225 MMcf of crude helium offered for sale, only 8,936 MMcf, or 56 percent, was taken. The four crude helium refiners took 8,586 MMcf, or 96 percent, of the total sold.

The BLM "open market" sales are not "market" sales at all, nor are they "open" to anyone who might wish to bid. For almost all the helium being sold, this sale process effectively creates an entitlement share for each entity that owned a facility with refining capability on the Helium Pipeline in the year 2000. Each refiner is guaranteed to

[10] See, for example, http://www.balloonsbycarolyn.com/download/1006HeliumMarketGarvey.pdf.

TABLE 5.2 Sell-off Helium Sales by BLM, 2003-2008

	Amount (MMcf)			Crude Helium Refiners				Other Purchasers		
Date of Sale	Offered	Sold	Not taken	Keyes	BOC	Prax	AP	Lin	Math	AL
3/03	1,640	1,640	0		834	76	680			50
11/03	2,100	675	1,425		550	75		50		
10/04	2,100	490	1,610		150	160	160	20		
4/05	1,610	300	1,310		150	100		50		
9/05	1,310	600	710	40		200	360			
10/05	2,100	1,565	535		485	500	500	80		
FY07, Q1	525	505	20		140	150	180			
FY07, Q2	525	380	145			170	180			
FY07, Q3	690	690	0	30	240	170	245		5	
FY07, Q4	525	455	70	20	200	50	180		5	
FY08, Q1	525	396	129	46		170	180			
FY08, Q2	525	469	56	49	150	170	100			
FY08, Q3	525	381	144	36		200	130			15
FY08, Q4	525	392	133	36	130		214			12
TOTAL	15,225	8,936	6,287	257	3,029	2,191	3,109	200	10	27

NOTE: Keyes, Keyes Helium, Inc.; BOC, BOC Group; Prax, Praxair, Inc; AP, Air Products and Chemicals, Inc.; Lin, Linde North America, Inc.; Mid, Midstream Energy Services, LLC; Math, Matherson Tri-gas, Inc.; AL, Air Liquide.
SOURCE: Available at http://www.blm.gov/nm/st/en/prog/energy/helium/helium_operators_information.html. Last accessed August 10, 2009.

get its share or any part of it for which it is willing to pay the fixed, noncompetitive price. Each refiner may seek a share larger than its entitlement but may or may not get the extra amount, depending on whether the other three refiners have asked for their full entitlement. While bidders other than the refiners can and do participate in the nonallocated part of a sale, such bidders are bidding not on price but for a share of the nonallocated crude. As a practical matter, a winning bidder has no way to get its purchase to market except by having a refiner refine and package it.

BLM Pricing Policy for Crude Helium

The 1996 Act mandated selling off the federally owned helium at a minimum crude price of approximately $47 per Mcf, with a yearly escalation of this minimum at the rate of increase in the preceding year's consumer price index. As this report was being written, the price charged by BLM was $64.75 per Mcf.[11]

[11]Available at http://www.blm.gov/nm/st/en/prog/energy/helium/helium_operators_information/crude_helium_price.html. Last accessed on July 1, 2009.

At the time the 1996 Act was enacted, the mandated minimum price for federally owned crude helium was at least double the typical price in contracts for the sale of privately owned crude helium. As discussed in the 2000 Report and in Chapter 1 of this report in the section "Review of the 2000 Report's Conclusions," it was anticipated that because of the long-term nature of those contracts, prices for privately owned crude helium would remain significantly below the price charged by BLM. This turned out not to be true.

After BLM began its sales of crude helium in earnest in 2004, private sector sellers of crude helium started to drive the prices at which they sold crude helium toward the BLM prices established by the 1996 Act. Assisted by surging demand and tight supplies, it now appears that private sector suppliers have been able to increase their prices such that the average private sector crude price is now on a par with the BLM price and in some instances exceeds it by up to 10 percent. Further, the escalation provisions of practically all U.S. and international crude or liquid helium pricing agreements are now tied to the BLM price.

Because the BLM crude price is now comparable to or even below the price of privately owned crude helium, federally owned crude helium from the Bush Dome Reservoir is no longer serving as a backup source of crude helium, as envisioned when the Federal Helium Reserve was originally developed (a vision essentially abandoned by enactment of the 1996 Act). Although BLM acted in good faith in setting the price of federally owned crude helium at the minimum price defined by the 1996 Act, its pricing policies no longer serve the interests of the U.S. taxpayers who financed the Federal Helium Reserve.

While direct evidence is sparse, general economic and business considerations suggest that BLM's pricing practices, because they provide ready access to relatively cheap crude helium to only a limited number of refiners, could easily distort the incentives of those who participate or might participate in the crude helium market, as follows:

- Refiners without access to federally owned crude helium are at a disadvantage in participating in the marketing of federally owned helium.
- Because the BLM selling price now effectively establishes the price for crude helium, market forces that otherwise might increase crude helium prices and encourage the development of additional sources of crude helium have lost their influence. This includes nearby private producers in smaller fields with helium-bearing natural gas that might otherwise develop those fields, connect to the Helium Reserve pipeline and supply additional privately owned crude helium to the refineries on the pipeline.
- To the extent that current crude helium pricing depresses the prices of refined helium, incentives are weakened for users of refined helium to invest in alternative gases and/or to invest in conservation and reuse of refined helium.

The unusual structure of the Federal Helium Reserve, with its publicly owned pipeline (the Helium Pipeline) that links privately owned refineries to a publicly owned reservoir of crude helium (the Bush Dome Reservoir), makes it difficult for BLM to develop policies that would establish a market-based price for the Bush Dome crude helium. Selling the Bush Dome crude helium in periodic auctions, for example, would require that purchasers of that crude helium have guaranteed access to the refinery capacity owned by the four major industrial-gas firms on the Helium Pipeline or some other mechanism for acquiring, indirectly, helium purchased in any sale. However, absent a mechanism for those refiners to process any crude purchased at auction or otherwise acquire credit for helium purchased, there is little incentive for purchasers other than the four firms operating these refineries to bid on BLM crude helium.

Nonetheless, there are a number of ways in which BLM could establish a more competitive process for selling federally owned crude helium. BLM could use surveys and analytical studies to approximate a competitive price for crude and set it as the minimum bid. More information on items to consider in evaluating different auction approaches to the sale of crude helium can be found in Appendix E. The Secretary of the Interior also could seek authority to require refiners connected to the BLM system to refine crude helium purchased by other parties when they have the capacity to do so, or BLM could develop alternative mechanisms for delivery of purchased helium, perhaps in the form of a crediting system whereby successful bidders would be entitled to delivery of refined helium by one of the parties with access to the Helium Pipeline.

In summary, the current sale and pricing mechanism for federally owned crude helium significantly distorts the market and promotes inefficient utilization of a publicly owned reservoir of an irreplaceable resource with very few substitutes in some applications. These market distortions have encouraged the extraction of crude helium from the Bush Dome Reservoir and the exploitation for private profit of this reserve by a small number of firms having refineries connected to the publicly financed Helium Pipeline. The pricing for Bush Dome crude helium could also discourage the development of alternative sources of crude helium supply, resulting in the venting of crude helium from natural gas fields in the United States and abroad. Indeed, it is plausible that some of the sharp price increases and supply disruptions from 2005 to 2008 reflected the suppression of market incentives—by, for example, substituting other gases for helium and investing in conservation and recovery—that might otherwise have dampened market disruptions.

Efficiency and Conservation Benefits of the Flywheel

The 2000 Report defined the Helium Reserve as a "flywheel" in the following sense:

> The private refiners in the Hugoton-Panhandle complex that are on the federal pipeline rely on the Cliffside facility to act as a flywheel. Natural gas extraction companies generally sell crude helium to helium refiners on the basis of long-term (e.g., 20-year) take-or-pay contracts, which stipulate that the refiners must buy a negotiated quantity of helium per year from natural-gas producers for an extended period of time regardless of whether they store it, refine it, or vent it. The refiners with access to the pipeline store all of their crude helium in the Cliffside facility and remove and refine it as necessary. Any crude helium in excess of current market demand will thus remain in the Cliffside facility and become part of the company's private stockpile. The amount of helium ultimately produced from the Hugoton-Panhandle complex would certainly be less if the Cliffside facility were not available. (NRC, 2000, p. 6)

This working definition of the flywheel concept suggests that the existence of the Bush Dome Reservoir prevents refiners from wasting helium (mainly by venting it), because it assumes that these refiners have no facilities of their own to store crude helium during periods of low demand for refined helium.

The flywheel system described in the statement of the committee that wrote the 2000 Report seems to imply a pattern of fluctuating deposits and withdrawals by helium refiners into and out of the Bush Dome Reservoir. Figure 5.1 indicates that such fluctuations in deposits and withdrawals arguably were present for much of the period between roughly 1975 and 1996 or 1997. Since the late 1990s, however, refiners have largely ceased making significant deposits into the Bush Dome Reservoir.[12] One reason why such deposits no longer are taking place might be because the amount of helium being produced from the natural gas fields connected to the Helium Pipeline has been decreasing as those fields mature. Table 4.3 indicates that, as of 2008, the crude helium available from those fields is only 38 percent of the capacity of the helium refineries connected to the Helium Pipeline. Even after including the amount of crude helium that the 1996 Act expects BLM to sell each year, the total helium available to those refineries is only 82 percent of their refining capacity.

Since late 2008, however, anecdotal information suggests that global demand for crude helium has collapsed below the amount being supplied from other sources in the Hugoton-Panhandle complex to the refineries on the publicly financed Helium Pipeline. The weak demand could soon lead to increased deposits of crude helium from these private firms into the Bush Dome Reservoir. Such deposits would reduce the venting of crude helium from natural gas wells in the Hugoton-Panhandle complex, thereby contributing to crude helium conservation in a fashion that is broadly consistent with the statement just quoted from page 6 of the 2000 NRC Report.

[12]The prepublication version of this report indicated that injections occasionally were made to maintain the pressure and purity of the stored helium. Following issuance of this report, BLM informed the committee that injections are not made for those purposes and so this language was removed.

Briefings to this committee by representatives of the companies owning refining facilities connected to the Helium Pipeline suggested a second possible efficiency gain from the Federal Helium Reserve that differs somewhat from the flywheel mechanism discussed above. Planned and unplanned refinery shutdowns pose challenges to the production efficiency of any helium extraction complex. The Helium Reserve infrastructure enables BLM to regulate deliveries of crude helium to refiners in ways that accommodate such shutdowns and avoid the loss of helium from the natural gas wells connected to the Helium Pipeline and the Bush Dome Reservoir.

One way to assess the argument that the Federal Helium Reserve enhances the efficiency of crude helium recovery would be to compare the efficiency of extraction of crude helium (or, equivalently, the fraction of recoverable helium that is vented) from the Hugoton-Panhandle complex by refiners on the Helium Pipeline with the extraction efficiency of other large crude helium production sites not connected to the Helium Reserve, such as the ExxonMobil complex in Wyoming. The committee that wrote the 2000 Report apparently had no such data. The current committee sought similar data, which does not appear to be available in public records. In the absence of such data, the 2000 Report's claims that the BLM flywheel has enhanced helium recovery from the Hugoton-Panhandle complex lack an empirical foundation.

The current status and operation of the Bush Dome Reservoir also appears to limit its use as a flywheel. For the flywheel to operate effectively, crude helium owned by private operators of wells and refineries on the Helium Pipeline and injected into the Reservoir must be recoverable during periods of higher demand and/or lower crude helium supply. This, in turn, requires that the Bush Dome Reservoir's helium injection wells be able to produce high-quality crude helium, with no invasion into the wells by native gas (the gas originally in the reservoir—mostly methane). At present, however, the intermixing of native gas with crude helium in significant parts of the Bush Dome Reservoir means that only one helium injection well, Bi-A6 (see the subsection entitled "Validation"), can produce relatively high-quality crude helium.[13] The capacity for production from well Bi-A6 declined from 3 MMcf per day in earlier years to 1.9 MMcf per day because of the decline in reservoir pressure. This raises a question: Do the Helium Reserve facilities that extract helium, increase its concentration, and pressurize the crude helium for delivery to the refineries have the surplus capacity to provide privately stored helium on top of the helium sold pursuant to the 1996 Act that BLM currently is delivering to the refiners?

[13]The high quality of crude helium from Bi-A6 is also related to the fact that some crude helium is still injected into the well during the year, during periods of low demand or because of a planned program to maintain crude helium quality. These injections are not being made into the other wells.

BLM Management of the Bush Dome Reservoir

The 1996 Act gave BLM the responsibility for managing the drawdown of federally owned crude helium in the Bush Dome Reservoir to 600 MMcf by 2015. It also mandated that extraction of crude helium from the Bush Dome Reservoir take place on a straight-line basis, requiring a very different approach to managing the drawdown than is employed for all known commercial subterranean gas deposits. This section assesses BLM's management of these complex tasks. First the committee discusses BLM's analysis and modeling of the Bush Dome Reservoir, activities that are critical to efficient extraction of the crude helium in the reservoir over the years. It then considers the issues for efficient reservoir management created by the 1996 Act's mandate that the crude helium in the Bush Dome Reservoir be extracted on a straight-line basis, defying the guidance of most experts on reservoir management. Finally, the 1996 Act's failure to address how the Helium Reserve is to be managed after 2015 raises other serious issues for BLM and for the United States, which the committee discusses in the last section of this chapter.

Challenges in Managing the Reservoir

To understand the magnitude of BLM's management task, it is useful to describe the characteristics of the Bush Dome Reservoir.[14] Figure 5.3, a schematic cross section, depicts the processes of crude helium storage and retrieval from the reservoir. When crude helium is injected into the reservoir, the influence of gravity tends to cause it to rise relative to other gases present. However, different layers in the reservoir have different fluid conductivities, so the helium moves further in some layers than in others as it displaces the native gas. This uneven movement in the different layers promotes mixing of helium and native gas. Preservation of the quality of the crude helium in the reservoir requires that any such mixing be monitored carefully and, to the extent feasible, minimized.

When helium is recovered from storage in the Bush Dome Reservoir, it again moves unevenly in different layers. Some layers with unusually high flow conductivities may produce all the stored helium relatively quickly, while other layers

[14]The prepublication version of the report stated that the reservoir's characteristics differ greatly from most conventional natural gas fields or other naturally occurring petroleum deposits. After the issuance of that version of the report, BLM pointed out that the reservoir is similar to other naturally fractured dolomite/limestone petroleum reservoirs in the Texas Panhandle and Permian Basin. To avoid confusion, the language comparing the reservoir's characteristics to those of conventional gas fields or other naturally occurring petroleum deposits has been removed. The prepublication version of the report also stated that the helium is injected into the top of the reservoir. Helium is actually injected through several wells, some of which are not at the top of the reservoir, and so that language has been removed.

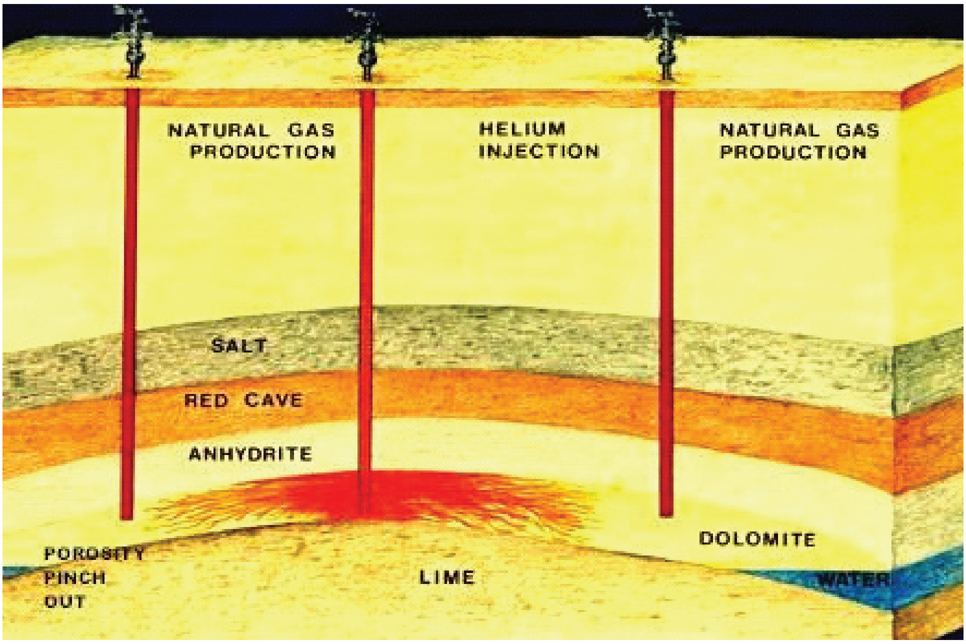

FIGURE 5.3 Cross section of the Cliffside field at the Bush Dome Reservoir illustrates key features of the helium storage project. Crude helium (red) is injected into the reservoir through injection wells and displaces native natural gas (yellow, mostly methane). The injected helium moves with different velocities in different layers of the reservoir, and mixes with the native natural gas. The reservoir is bounded on the north and east by a gas water contact (blue), and on the south and west by a porosity pinch-out. SOURCE: Bureau of Land Management, U.S. Department of the Interior.

may allow native gas to break through to the producing wells, reducing the helium concentration in the overall produced gas stream and promoting additional mixing of the helium and native gas remaining in the reservoir.

The cross section in Figure 5.3 shows water beneath the gas in the reservoir. As pressure in the reservoir drops during a prolonged period of sustained production (such as happened beginning in 2003), the water can expand and move into pore space formerly occupied by gas. When the water is sufficiently close to the area in the formation open for production by a well, it may "channel" or "cone" into the well bore and may reduce or altogether eliminate the ability of the well to produce gas.

BLM Contract with NITEC for Analysis of the Reservoir

To develop a more sophisticated understanding of the complex dynamics of the Bush Dome Reservoir, BLM contracted with an independent consulting firm, NITEC, LLC, to model the characteristics and future operational challenges associated with the Bush Dome Reservoir. Founded in 1995, NITEC is a petroleum exploration and production consulting firm in Denver. The company focuses on integrated (geological, geophysical, and engineering) reservoir studies, including reservoir simulation, and includes naturally fractured reservoirs as a specialty.

NITEC's contract with BLM was a sole-source one, and there is little evidence that BLM searched extensively for alternative sources of expertise.[15] In the committee's judgment, BLM should undertake a broader review of the capabilities of NITEC and seek out other sources of expertise for its management of the Bush Dome Reservoir. The committee suggests that any renewal of BLM's contract with NITEC should be considered on a competitive basis. By making this suggestion, the committee is not questioning the capability of either NITEC or staff members of BLM responsible for maintaining the reservoir. Rather, as discussed in more detail in the following section, even under the best scenario, efforts to model the reservoir are quite challenging and the committee believes that all reasonable steps be taken to ensure it is accomplished with all due care.

NITEC Models of the Bush Dome Reservoir

One of NITEC's first tasks was the development of a numerical simulation of the Bush Dome Reservoir. The main purpose of the simulation was to determine how BLM could best recover 98 percent of the federally owned helium in the reservoir, given that the helium is to be sold in equal annual volumes over 12 to 13 years pursuant to the terms of the 1996 Act. The total helium to be recovered during this time period is 29.9 Bcf, of which 28.5 Bcf is owned by the government and 1.4 Bcf is privately owned. The amount of helium to be left in the reservoir is 600 MMcf. These figures require an average production rate of 2.3 Bcf per year, or 6.3 MMcf per day, operating 365 days per year (or, more realistically, 6.57 MMcf per day for 350 days per year).

NITEC developed at least two models—one basic and then one more refined—in its studies. The first model was a material balance model[16] used in the inventory verification phase of the study. It allowed for multiple region-weighted pressures to establish representative field-average pressures and pressure-volume-temperature

[15]After the preparation of this report but prior to its final publication, BLM informed the committee that the original study was not a sole-source contract but was competitively bid. Five companies submitted bid packages and NITEC was chosen as the successful bidder. Subsequent contracting was completed as sole-source contracts with NITEC.

[16]The prepublication version of the report indicated that the first model was a tank model that assumes uniform pressure throughout. After release of that version of the report, BLM informed the committee that while a tank model was used in initial efforts to understand the reservoir, the first formal model results were obtained using a material balance approach.

estimates for native gas and crude helium gas injections. The volumes of original gas in the reservoir and helium in place in the reservoir were determined with this model.

NITEC's second model was a finite-difference reservoir model that used a commercially available reservoir simulator, often called a "compositional simulator," widely used in the petroleum industry. This simulator differs from a tank-type model in that the reservoir is divided into thousands of "cells" between which gas flows in response to pressure differences between adjacent cells. For each cell into which the reservoir is divided the simulator keeps track of the composition of four distinct components: helium, nitrogen, methane, and all other natural gas components lumped together. This component tracking is critical for determining the location of helium in the reservoir and for predicting when other components, such as methane, could break through into helium-producing wells.

The Bush Dome Reservoir is modeled as a naturally fractured formation. Most of the reservoir's flow capacity toward the producing wells occurs in the highly conductive fractures, but significant amounts of gas in the reservoir are also contained in the much less conductive rock matrix. Some of the fractures appear to be mostly "open" and therefore fully conductive; others appear to have been partially or totally filled with mineral deposits and therefore serve as flow barriers rather than flow paths. Special features of the reservoir simulator that NITEC used allow modeling of the naturally fractured characteristics of the reservoir. Figure 5.4 exemplifies the displays generated by this modeling.

Neither of NITEC's models of the Bush Dome Reservoir adequately analyzed the effects of an influx of formation water into the reservoir on the quality or quantity of recoverable crude helium.[17] In the opinion of the committee, the absence of such analysis is a significant deficiency in the NITEC models. As the committee notes below, the encroachment of water into various pockets of crude helium within the Bush Dome Reservoir has been a serious problem for reservoir management and, especially in the face of limited BLM funding, is likely to become even more serious with the passage of time, particularly after 2015.

***Data Used in the NITEC Models* (Weinstein, 2003)** Geological models of reservoirs such as Bush Dome are typically constructed from a combination of seismic

[17]The prepublication version of the report stated that neither of NITEC's models analyzed the effects of formation water flowing into the reservoir. That statement was not accurate and has been modified to indicate that the models do not adequately analyze the effects of formation water. The models permit the assessment of the effects of formation water on the reservoir, but in the absence of any historical evidence of how water has affected the reservoir, the models could not predict the appearance of the water nor how it would impact the reservoir's characteristics. As NITEC noted in its presentation to the committee (Weinstein, 2008), more information is needed about the sources of the water before water influx effects can be adequately incorporated into the models.

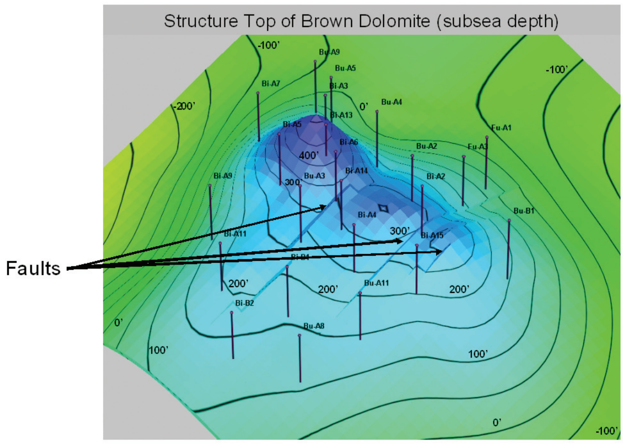

FIGURE 5.4 Three-dimensional structure map of the Bush Dome Reservoir, showing the placement of existing wells (identified in the form XX-X#) and calculated fault lines. The contour lines represent heights with respect to sea level. For reference, ground level is at approximately 3,500 feet. SOURCE: NITEC LLC.

data, which provide insight into structure, size, and flow barriers such as faults; geophysical log data, which provide insight into pore space distribution; and core data, which provide an understanding of rock types and flow conductivity.

The Bush Dome Reservoir, discovered in 1924, lacks data obtained with modern tools. In particular, modern seismic data and interpretations are not available. The geophysical logs available were for the most part outmoded. With only static data (data not related to flow of fluids in the reservoir), it is not possible to describe important features of the reservoir, including faults such as fractures and barriers. This means that high-conductivity flow paths and barriers to flow had to be inferred from observed production. Reservoir modelers almost always depend on observed performance to describe a reservoir, but in this case the dependence was unusually great. The uncertainty and ambiguity surrounding the performance predicted using the model are therefore greater than usual. Other locations of high-conductivity flow paths and flow barriers and different lengths and properties of these paths and barriers might have led to equally good or even better matches to observed data, but would have led to at least slightly different predictions of future performance.

Fortunately, NITEC had an unusually large amount of pressure data (6,650 measurements in 26 wells) and fluid composition data (2,844 helium concentration measurements). It was able to start with a geological model based on static data, such as seismic and well logs, and to adjust the model and place barriers and high-conductivity flow paths in the reservoir such that the available data were well matched. NITEC also adjusted reservoir volume (thickness and porosity) in local areas to improve the match between observations and calculations.

Production and injection rates and volumes were recorded throughout the life of the reservoir, as were compositions of produced and injected fluids. Injected volumes and rates were treated as known, as was the composition of injected fluids. Produced volumes were also treated as known, but compositions of produced fluids were treated as unknown, and matching observed and calculated fluid compositions was a key step in model calibration (determining the spatial distribution of gas and properties of the formation).

Stabilized pressures in individual wells of the Bush Dome Reservoir were measured at frequent intervals. In the tank-type modeling efforts, average pressures throughout the reservoir, along with total amounts of helium, nitrogen, methane, and other gases injected and produced, were used to determine total reservoir pore volume. In numerical simulator modeling, comparisons of observed and calculated pressures and produced gas compositions in individual wells were used to calibrate the model.

One difficulty in predicting future performance with a model like the one used by NITEC is that future production and injection rates must be known (i.e., assumed) and imposed by the model for each well. Pressures and fluid compositions in the production streams must then be calculated. If assumed production and injection rates for the wells are not achieved in practice, then predicted pressures and produced fluid compositions cannot be correct. Only by rerunning the model after more observations have been made and the actual rates have been imposed as boundary conditions in the model can the reservoir description be validated.

NITEC's Validation of Its Model NITEC validated its reservoir model (the spatial description of fluid contents, flow paths, and flow barriers) by comparing calculated and observed data such as compositions of produced fluids and stabilized pressures in each well for which data were available until it considered the match satisfactory. This process was used in 2002 to make initial predictions and was repeated in 2008 (and in earlier years), at which time the reservoir description was improved and alternative reservoir models were considered. Figures 5.5 and 5.6 show matches of pressures and helium concentrations for two of the more used wells on the reservoir. The figures show that the reservoir description used for the match in 2002 had to be modified to match pressure and helium concentration data observed between 2002 and 2008 (Weinstein, 2008).

Recently, well Bi-A9 ceased to produce gas because of the unexpected invasion of water, and well Bi-A3 began to produce water, limiting its ability to produce gas. As was noted earlier, NITEC's model failed to take into account that water might intrude into the reservoir, so this aspect of the description was oversimplified.

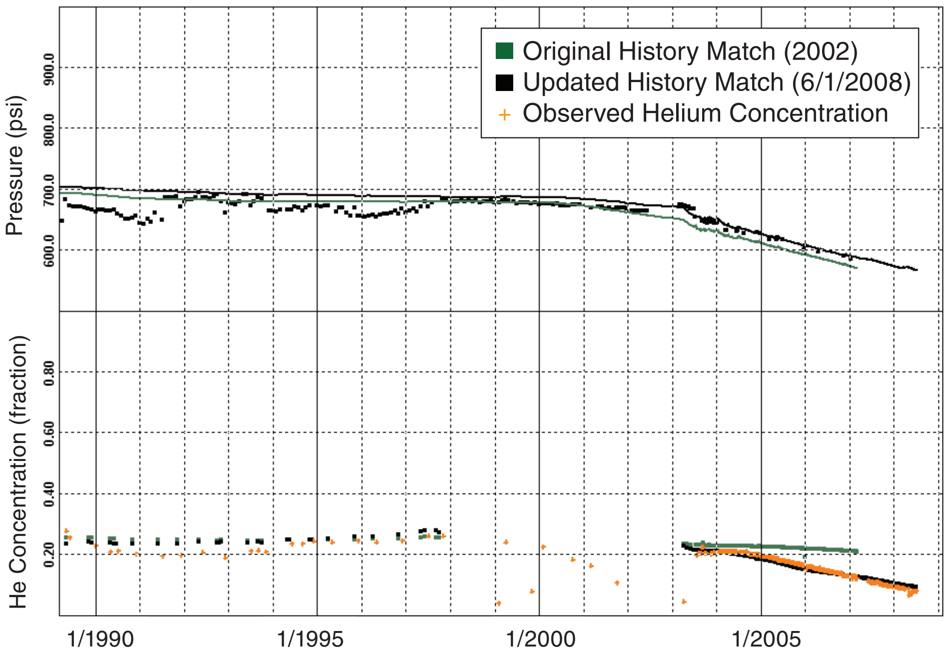

FIGURE 5.5 Matches of pressures and helium concentrations are shown for well Bi-A2. Observed data points are indicated; trends calculated using the original (2002) model are shown in green, and improved matches with the 2008 model are shown in black. Changes in trend, particularly notable in helium concentration predictions, were caused by changes in reservoir description (size and location of flow barriers and high conductivity flow paths). SOURCE: NITEC LLC.

Continued and more extensive intrusion of water could make NITEC's predictions unrealistically optimistic.

In its 2008 update of the model, NITEC investigated the implications of a major change in reservoir description. In the 2002 model, higher conductivity in the vertical direction allowed helium to move vertically to the top of the formation. The 2008 alternative model restricted the vertical movement of helium—that is, relatively lower vertical conductivity—with the result that helium moved further into the reservoir from the injection area. The quality of historical comparisons of helium concentrations and well pressures was as good in 2008 as it had been earlier with higher vertical conductivity, so there is no basis at present for preferring one reservoir description over the other (Weinstein, 2008). Unfortunately, the choice of one or the other description of the reservoir will greatly affect its future management. The conductivity in the reservoir and the associated vertical movement of crude helium will affect both the location of crude helium during the final

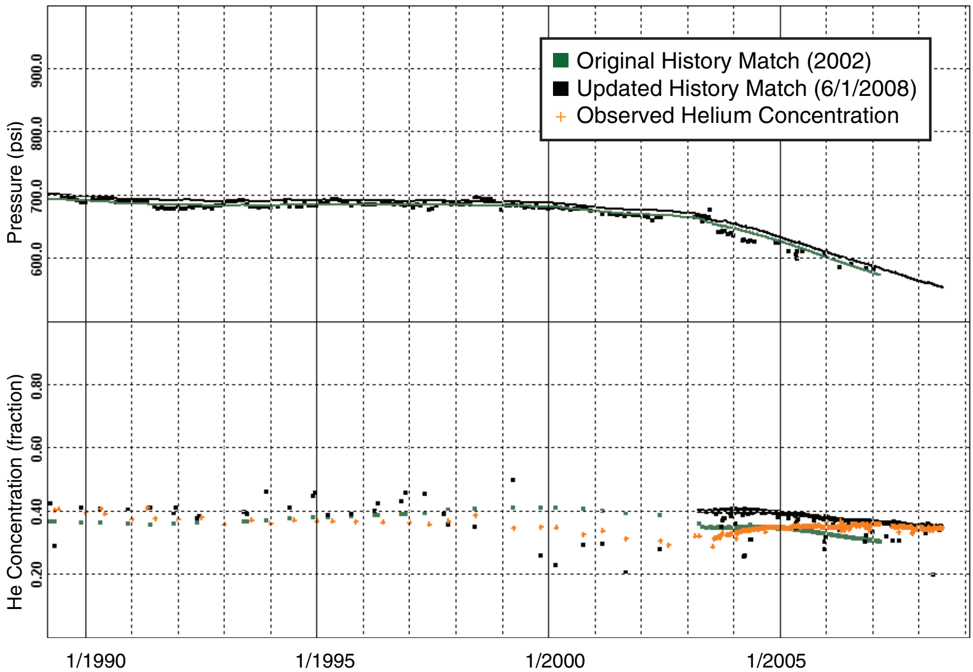

FIGURE 5.6 Matches of pressures and helium concentrations are shown for well Bi-A7. Observed data points are indicated; trends calculated using the original (2002) model are shown in green, and improved matches with the 2008 model are shown in black. Changes in trend, particularly notable in helium concentration predictions, were caused by changes in reservoir description (size and location of flow barriers and high conductivity flow paths. SOURCE: NITEC LLC.

years of production and the location of the 600 MMcf of helium that the 1996 Act directs should be left in the reservoir after 2015.

NITEC's Performance Predictions In 2008, as in previous years, NITEC used its model to predict future reservoir performance under several different scenarios, which are described in Table 5.3 (Weinstein, 2008).

Figure 5.7 shows helium production under three scenarios: the base case and cases F and G. It shows that case G, which assumes pipeline and field compression are added and that six new wells are drilled, most nearly maintains the target helium production rate from the field. With current facilities, target rates can be maintained only through 2011. Although NITEC now acknowledges that water influx rates will increase as reservoir pressure declines and that water production is likely to limit productivity in other wells, it has not incorporated this probability into its forecasts.

TABLE 5.3 Six NITEC Scenarios

Case	Description
Base	Current facilities. Maintain 6.3 MMcf per day withdrawal rate as long as possible.
D	Add pipeline compressor in October 2009.
D2	D + add field compressor in October 2010.
D3	D2 + maintain maximum rate in well Bi-A6 to October 2010; reinject until February 2010.
F	D3 + drill three new wells in 2010 and another three wells in 2011.
G	F + hold well Bi-A6 in reserve and reinject as long as possible.

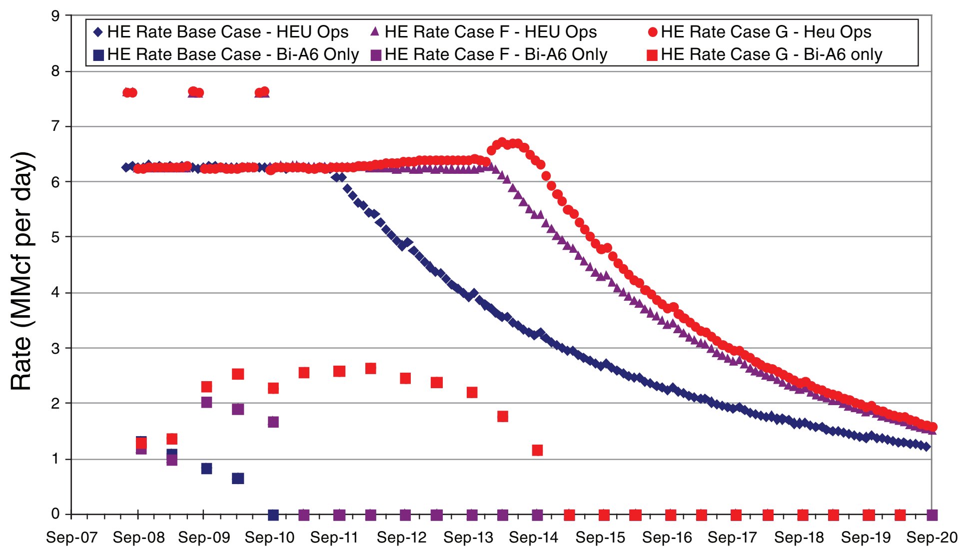

FIGURE 5.7 Forecast helium withdrawal rates for the base case (no changes to current facilities) and in case F (pipeline and field compression, 6 new wells) and case G (compression, new wells, and special handling of well Bi-A6). For each of these cases, forecasts are provided for production rates obtained by operating the Helium Enrichment Unit (HEU Ops) and by operating well Bi-A6 only. Case G maintains the required production rate longer than others. SOURCE: NITEC LLC.

NITEC'S Recommendations On the basis of these forecasts, NITEC recommended that BLM take the following actions (Weinstein, 2008):

- BLM should address the constraints on the productivity of well Bi-A3, which are caused by the intrusion of water.
- BLM needs to start upgrading facilities soon, so that compression is in place before well rates start to decline owing to the decline in compression.

- BLM needs to drill additional wells to improve recovery and to assure that helium production can meet its targets in the face of well aging and declining reservoir pressure.
- The Cliffside Helium Enrichment Unit operated by the CRLP has constraints that limit helium production. If these constraints can be mitigated, targets should be more attainable, but additional runs with the simulator will be required.

COMMITTEE'S SUPPLEMENTAL RECOMMENDATIONS

NITEC also noted in late 2008 that the Bush Dome Reservoir faced unusually high demand for crude helium and suggested that a series of steps be taken to reduce limits on production and improve the quality of the crude helium being extracted. NITEC's observations are persuasive and led the committee to make three additional recommendations to supplement Recommendation 4 in Chapter 1:

Recommmendation 4a. BLM should encourage the members of the CRLP to study and either remove the constraints on helium production in the crude helium enrichment unit or find a more economical alternative to increase the capacity of the unit.

Recommmendation 4b. BLM should implement NITEC's recommendations discussed in the section immediately preceding this section. These recommendations include:

—Short-term solutions
- **Add compression to well Bi-A6.**
- **Work over well Bi-A3 (currently rate-limited owing to water production) to increase productivity from 1 MMcf per day to more than 2 MMcf per day.**

—Medium- to long-range solutions
- **Upgrade production capability with compression and new wells.**
- **Reduce constraints imposed by the crude helium enrichment unit.**
- **Encourage owners of helium refineries to improve their plants' ability to process lower quality crude helium.**

Recommmendation 4c . Because an emergency situation (helium production shortfall) could arise at any time, BLM should avert this risk by upgrading facilities in the field and crude helium enrichment unit as soon as possible.

Several significant uncertainties and challenges remain for BLM's management of the Bush Dome Reservoir, according to information presented by NITEC (Weinstein, 2003, 2008). The accuracy of the reservoir description that is the basis for the NITEC model is uncertain. Because only older seismic and geophysical log data were available, NITEC had to at first base critical parts of its reservoir description on matches of observed pressures and helium concentrations in producing wells. Now, however, NITEC has obtained an equally good alternative match and associated reservoir description in which the distribution of helium in the reservoir differs substantially from that in the earlier reservoir description. Thus, predictions using the model are uncertain, and the uncertainties will only increase as the amount of helium remaining in the reservoir diminishes. These uncertainties are compounded by not knowing the degree of vertical conductivity of fluids within the reservoir. Does helium injected in lower parts of the reservoir rise toward the top or does it remain in the reservoir layers near the point where it was injected?

There are additional possibilities that might be considered for increasing the production capacity of the reservoir not proposed by NITEC. For example, horizontal wells might be able to increase production (and injection) capacity substantially at any given pressure difference between the surface and the reservoir. Fewer horizontal wells, placed strategically, could be a better alternative from the standpoint of both economics and dependable spare capacity in the Bush Dome Reservoir. Nor do NITEC's proposals provide any spare capacity, which could be needed if old wells in the field have mechanical problems, if water influx increases and causes productivity problems, or if the forecasts are simply overoptimistic because of incorrect details in the reservoir description.

STRAIGHT-LINE EXTRACTION MANDATE FOR BUSH DOME CRUDE HELIUM

This section evaluates the consequences, from a resource-management perspective, of the mandate in the 1996 Act that substantially all of the helium in the Federal Helium Reserve must be sold off on a straight-line basis by 2015. This is not a realistic production plan, because it is not feasible to continue to add wells and/or compression to the field. Reservoir pressure is declining, and maintaining a straight-line drawdown will become increasingly cost-prohibitive and, eventually, physically impossible. This can be seen from the reservoir simulations that have been done on the field (see, for example, Figures 5.5 and 5.6). Additionally, the aggressive production strategy could degrade reservoir properties, making it even more difficult to follow the strategy (Weinstein, 2008).

Best practices for economically efficient resource extraction (Chermak et al., 1999) include extraction rates that vary, usually declining over the economic life of a deposit. This approach avoids unnecessary pollution of the deposit by other liquids such as water, utilizes the natural pressure of a reservoir to extract the resources more efficiently, and avoids leaving substantial quantities in peripheral or less accessible portions of the reservoir. The language of the 1996 Act mandating straight-line extraction could therefore lead to inefficient exploitation of this taxpayer-funded resource.

If cost recovery is the ultimate objective, imposing straight-line drawdown is inappropriate. Instead, an objective of maximizing production within the constraint of cost recovery would add more flexibility. This would allow for a declining production path over time and might require fewer new wells. It would also allow for taking reservoir characteristics into account in the production plan and would consider the potential for reservoir degradation due to overly aggressive production. Appendix F contains a more detailed discussion on drawdown options.

BLM MANAGEMENT OF THE BUSH DOME RESERVOIR AFTER 2015

Finally, the 1996 Privatization Act is silent on policies for management of the Cliffside storage facility and the BLM pipeline after 2015, the mandated date for disposal of the crude helium reservoir. It is virtually certain that substantially more than 600 MMcf of crude helium will remain in the Bush Dome Reservoir by the end of 2015; indeed, most current projections estimate that this target will not be achieved until 2020 at the earliest. If BLM is unable to develop a market-based approach to pricing its sales of crude helium—and even if it does, given uncertainties about future prices and the capacity of the BLM pipeline—2016 may arrive with more than 600 MMcf in the Bush Dome Reservoir and incomplete retirement of the facilities' debt. What is to be done with the remaining crude helium? How will BLM's operations beyond 2015 be financed? As noted elsewhere, the progressive exhaustion of non-Bush Dome sources of crude helium in the Hugoton field also means that maintaining refinery capacity for the next decade or more poses additional challenges for which responses must be developed very soon.

The issues raised by the high probability that the Bush Dome Reservoir will contain significantly more than 600 MMcf by 2015 and by the possibility that the Helium Reserve's debt may not be retired before 2015 go well beyond the study charge to this committee. No matter the scope of the charge, these issues urgently require study. They will almost certainly need additional legislative or policy guidance from the Congress, senior policymakers within the Interior Department, and perhaps even the White House Office of Science and Technology Policy.

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Appendixes

Appendix A

Statement of Task

The study will determine whether selling off the U.S. Helium Reserve in the manner prescribed by law has had any adverse effect on U.S. scientific, technical, biomedical, and national security users of helium. To provide a meaningful context for this effort, the study will examine the helium market and the helium industry supply chain.

The study committee will address the following tasks:

1. Review the report "The Impact of Selling the Federal Helium Reserve" (NAP, 2000) and compare projected expectations with actual outcome. Determine the reasons for the differences.
2. Examine the availability and reliability of worldwide supply, technical opportunities to increase that supply—such as through improved recovery—and the relationships among supply, demand, and market price.
3. Assess the current and projected U.S. marketplace for refined helium, including worldwide helium demand by industrial and other users. Assess the role of private industry in future conservation efforts.
4. Assess the current "flywheel" concept for operating the Reserve. Develop scenarios for how the Reserve might be used to meet future helium demand.
5. Assess the role that organizational and financial factors play in meeting the goals of the Federal Helium Program. Identify measures that would enable the Program to respond more effectively to the dynamics of the helium industry.

Appendix B

Biographies of Committee Members

Charles G. Groat, ***Co-Chair,*** is the John A. and Katherine G. Jackson Chair in Energy and Mineral Resources, Department of Geological Sciences, and professor of geological sciences and public affairs at the University of Texas at Austin. He received an A.B. in geology from the University of Rochester, an M.S. in geology from the University of Massachusetts, and a Ph.D. in geology from the University of Texas at Austin. Dr. Groat has over 25 years of involvement in geological studies, energy, and minerals resource assessment, ground-water occurrence and protection, geomorphic processes and landform evolution in desert areas, and coastal studies. From 1998 to 2005 he served as the 13th director of the U.S. Geological Survey (USGS). At the USGS he emphasized integrated scientific approaches to understanding complex natural systems and the use of these understandings in management decisions. Dr. Groat is a member of the Geological Society of America, the American Association for the Advancement of Science, the American Geophysical Union, and the American Association of Petroleum Geologists.

Robert C. Richardson, ***Co-Chair,*** is the F.R. Newman Professor of Physics and the vice provost for research at Cornell University. He received a B.S. and an M.S. in physics from Virginia Polytechnic Institute. After serving in the U.S. Army, he obtained his Ph.D. from Duke University in 1966. He is a member of the governing board at Duke University, the American Association for the Advancement of Science, and Brookhaven Science Associates. Dr. Richardson has served as chair of various committees of the American Physical Society (APS) and recently completed a term on the governing board of the National Science Board. Dr. Richardson was awarded the Nobel prize for the discovery that liquid helium-3 undergoes a pairing transition similar to that of superconductors. He has also received a Guggenheim fellowship, the Eighth Simon Memorial Prize (of the British Physical Society), the Buckley Prize of the APS, and an honorary doctorate of science from the Ohio State University. He has published more than 95 scientific articles in leading research journals.

Robert R. Beebe (NAE) is a former senior vice president of Homestake Mining Company. He has broad expertise in mineral economics and public policy, mineral processing and extractive metallurgical research, and mining and mineral project development and administration. Mr. Beebe is a member of the Society for Mining, Minerals and Exploration, and in 2001 he was named a national associate of the National Academies.

John R. Campbell is president and CEO of J.R. Campbell & Associates, Inc. Prior to forming this consulting firm in 1981, John Campbell held management and executive positions with two leading industrial gas companies. His last position was as executive vice president and chief operating officer of Burdox, Inc. (later, AGA Gas, Inc., and now part of Linde AG). In that company, then the largest of the independent U.S. regional gas companies, Mr. Campbell was responsible for day-to-day operations. Before that, he worked in a variety of gas-related marketing and management positions for Air Products & Chemicals, Inc. Mr. Campbell has an engineering degree from Rensselaer Polytechnic Institute and an M.B.A. from Lehigh University. He served as president and board member of the International Oxygen Manufacturers Association and has been active in the Compressed Gas Association, the Gases & Welding Distributor Association, and several associations of gas-using industry and service sectors.

Moses H. Chan is Evan Pugh Professor of Physics at Pennsylvania State University. He received a B.A. from Bridgewater College and M.S. and Ph.D. degrees from Cornell University. His research interests are phase transitions, particularly quantum fluids and solids at cryogenic temperatures, reduced dimensionalities, and the presence of disorder. Dr. Chan received the Fritz London Memorial Prize in Low-Temperature Physics (1996), the John Simon Guggenheim Fellowship (1986), the Senior Research Fellowship of the Japan Society for the Promotion of Science (1982). Dr. Chan is also a fellow of the American Physical Society.

Janie M. Chermak is a professor of economics at the University of New Mexico. Her research interests focus on the economics associated with natural resources and the environment and include studies of natural gas markets and regulation, modeling the uncertainties associated with natural gas supplies, and the economics of exhaustible resources. Portions of her work involve dynamic optimization modeling. She has held a variety of professional appointments, including as an economic and geologic analyst for the American Welding Society, the Homestake Mining Company, and the Natural Gas Corporation of California. In 1994, she received the Outstanding Research Achievement Award from the Naval Postgraduate School.

Carol A. Dahl is a professor in the Division of Economics and Business and director of the Joint International Degree Program in Petroleum Economics and Management at the Colorado School of Mines. Her research centers on international energy markets, government energy policy, and energy market modeling and forecasting techniques. She received a Ph.D. in economics from the University of Minnesota and a B.A. in economics from the University of Wisconsin.

Thomas Elam is the helium program manager for NASA fluids management and the technical representative for consolidated helium contracts for NASA. He received a B.S. in mechanical engineering from Rutgers University. Mr. Elam coordinates technical issues of the NASA helium contracts with NASA helium use locations and the helium supply companies. He follows the market conditions affecting availability and costs of helium and communicates supply and cost threats to NASA programs and customers. Mr. Elam is the NASA technical liaison for the BLM helium program and commercial helium suppliers.

Allen M. Goldman (NAS) is Regents Professor of physics at the University of Minnesota. He received an A.B. in chemistry and physics from Harvard University and a Ph.D. in physics from Stanford University. Dr. Goldman's research interests are the properties of superconductors and selected magnetic materials in the configuration of thin films. Dr. Goldman received the Fritz London Memorial Prize for low-temperature physics in 2002. Dr. Goldman is a fellow of the American Physical Society and the American Association for the Advancement of Science and a member of the National Academy of Sciences.

Norman E. Hartness is an independent consultant for EOP Group, Inc., a natural resources and environmental policy consulting firm. In this capacity, he contributes economic and policy analysis in a variety of natural resources areas. Mr. Hartness retired from the Office of Management and Budget (OMB) as special assistant (economic analysis) to the OMB's deputy associate director for the Natural Resources Division. In this position he provided technical consultation and other assistance to budget examiners throughout the Natural Resources Division in designing and implementing cost benefit studies, special studies, and other policy analyses. Mr. Hartness worked on programs in all areas of Division responsibility: agricultural, environmental, civil works, and Department of Interior programs. He received the Bureau of Budget Award for Professional Achievement (1970), the OMB Award for Outstanding Service (1985), the OMB Award for Outstanding Service (1990), and the OMB Natural Resources Division Award (1992). Mr. Hartness studied government at Harvard College, receiving the A.B. degree, and studied at the graduate level in the Department of Economics, University of Maryland.

W. John Lee (NAE) is the Regents Professor and holds the L.F. Peterson Endowed Chair in the Harold Vance Department of Petroleum Engineering at Texas A&M University. Dr. Lee recently worked in Washington, D.C., as an academic fellow for the Securities and Exchange Commission on the issue of oil and gas reserves and in the natural resources group, which includes mining. After receiving B.Ch.E., M.S., and Ph.D. degrees from the Georgia Institute of Technology, Dr. Lee worked for the Reservoir Studies Division of Exxon Production Research Company. His work focused on simulator reservoir studies of leading Exxon reservoirs in Saudi Arabia, Venezuela, and South Texas. Later he joined and eventually headed the major fields study group of Exxon Company, USA, where he supervised integrated field studies of Exxon's largest domestic reservoirs. He joined Texas A&M University in 1977. Dr. Lee was elected to the Russian Academy of Natural Sciences in 2006. He received the Society of Petroleum Engineers (SPE) DeGolyer Distinguished Service Medal, the society's top service award, in 2004, the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME)/SPE Anthony F. Lucas Gold Medal, the societies' top technical award, in 2003, and the AIME Mineral Industry Education Award in 2002.

Albert Migliori is head of the Resonant Ultrasound Spectroscopy Magnet Laboratory group, part of the National High Magnetic Field Laboratory at Los Alamos National Laboratory (LANL). He received a Ph.D. from the University of Illinois in 1973 and, following a postdoctoral position at LANL, became a staff member there in 1976. He has remained with LANL since that time. He is the codiscoverer of acoustic heat engines and has won numerous awards for his work in resonant ultrasound spectroscopy. His expertise includes work on the Mossbauer effect, the design of liquid working fluid heat engines, and studies of superconductors and Kondo systems, insulators, and semimetals. Dr. Migliori was elected an APS Fellow through the Forum on Industrial and Applied Physics in recognition of his work on resonant ultrasound spectroscopy and its application in materials physics and technology. He is also a fellow of LANL, holds 21 patents, and has written more than a hundred publications, five book chapters, and one book.

David C. Mowery is the William A. and Betty H. Hasler Professor of New Enterprise Development at the Walter A. Haas School of Business at the University of California at Berkeley and a research associate of the National Bureau of Economic Research.

He received bachelor's and Ph.D. degrees in economics from Stanford University and was a postdoctoral fellow at the Harvard Business School. His research addresses the economics of technological innovation and the effects of public policies on innovation; he has testified before congressional committees and served as an adviser for the Organization for Economic Cooperation and Development, federal agencies, private companies, and industrial firms. Dr. Mowery has published numerous academic papers and has written or edited a number of books, including *"Ivory Tower" and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act, Paths of Innovation: Technological Change in 20th-Century America*, and *The International Computer Software Industry: A Comparative Study of Industry Evolution and Structure.* His academic awards include the Raymond Vernon Prize of the Association for Public Policy Analysis and Management, the Economic History Association's Fritz Redlich Prize, the Business History Review's Newcomen Prize, and the Cheit Outstanding Teaching Award.

Michael Prats (NAE) is president of Michael Prats & Associates, Inc., a small reservoir engineering consulting firm. Earlier, Mr. Prats worked continuously for or with Shell Oil Company affiliates until his retirement in 1989. He holds a B.S. in physics (with honors) and an M.A. in physics, both from the University of Texas at Austin. In addition to thermal recovery processes (his main field), his areas of expertise include (l) displacement processes, (2) hydraulic fracturing, (3) reservoir characterization, (4) unconventional raw materials (such as coal and oil shale), and (5) reservoir compaction. Mr. Prats holds more than 33 patents, most of them related to oil recovery techniques. He has served as the director of the Society of Petroleum Engineers (SPE), as a senior technical editor at SPE, and as chairman of numerous SPE committees. He is an Honorary Member of AIME and the SPE, from which he received the 1974 SPE Lester C. Uren Award Certificate, the 1993 AIME Anthony F. Lucas Gold Medal, and the Thermal Recovery Distinguished Achievement Award in 1991 and was named an AIME Pioneer in Enhanced Oil Recovery in 1986 and in Hydraulic Fracturing in 2005. He was elected to the Russian Academy of Natural Sciences, from which he received the Kapitza Gold Medal in 1995, and to the Mexican National Academy of Engineering as corresponding member.

J. Benjamin Reinoehl is principal and part owner of RMW Solutions. He received a B.S. in engineering and an M.B.A. from Lehigh University. Before retiring, he worked at Air Products and Chemicals, Inc., as director of business development, where he was responsible for the worldwide helium and hydrogen product lines and the development of new sources for these gases. Mr. Reinoehl developed the first supply of liquid helium in Algeria from LNG-sourced tail-gases. He received the 1993 Air Products Chairman's Award for Excellence. His expertise is in helium recovery, purification, liquefaction, and marketing; helium sourcing development, evaluations, and projects; hydrogen production, purification, liquefaction, and marketing; and industrial gases economic evaluations and project cost estimates.

Igor Sekachev is group leader of the Vacuum Systems and Cryogenic Engineering Group at TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics. In this capacity, Mr. Sekachev works with helium storage, use, and distribution for a large science research facility and brings expertise in cryogenics engineering. Mr. Sekachev has over 20 years of engineering physics experience in vacuum, cryogenics, and mechanical, electrical, and electromechanical instrumentation design and construction. He is familiar with the commissioning, operation, and maintenance procedures for equipment and instrumentation used in nuclear and particle physics, accelerators, and industrial installations. He also has extensive international contacts in cryogenics in the United States, Europe, and Asia. He has an M.Sc. in engineering physics from Moscow Engineering Physics Institute (a university).

Thomas A. Siewert leads the Structural Materials Group in the Materials Reliability Division of the National Institute of Standards and Technology. He received his Ph.D. in metallurgy from the University of Wisconsin (following earlier degrees in applied math and physics, and materials science), spent about 10 years as an electrode developer in the welding industry, and currently has more than 20 years of government service as a researcher. Dr. Siewert is a fellow and honorary member of the American Welding Society and past chair of the American Council of the International Institute of Welding. He is an adjunct professor in the Center for Welding and Joining Research at the Colorado School of Mines, teaches several courses a year in material forensics for OSHA inspectors, and is a coeditor of the ASM *Handbook on Welding.*

Mark H. Thiemens (NAS) is a professor of chemistry and biochemistry and dean of the Division of Physical Sciences at the University of California at San Diego. He developed the mass-independent fractionation process for stable isotopes and used the process to gain a deeper understanding of Earth's atmospheric composition and evolution. A portion of his work involves understanding the quantum-level physical and chemical mechanisms of the process. He has also used this process to study a wide array of phenomena, including the origin and evolution of the solar system; the source and transformation of greenhouse gases in the troposphere; the chemistry of the stratosphere and mesosphere, especially the ozone cycle; the chemistry of the ancient martian atmosphere; the origin and evolution of oxygen and ozone and life in Earth's Precambrian; the history of seawater over millions of years; and changes in the oxidative capacity of the atmosphere.

Appendix C

Meeting Agendas

FIRST MEETING
WASHINGTON, D.C.
JUNE 24-25, 2008

Tuesday, June 24, 2008

Closed Session

Open Session

1:30 pm	Introductions	Chip Groat, *Co-Chair* Bob Richardson, *Co-Chair*
1:40	Presentation from the Sponsor	Joe Peterson, Bureau of Land Management (BLM)
3:00	Break	
3:15	Panel Discussion with Agencies that Fund Government Research	George Madzsar, National Aeronautics and Space Administration (NASA) Joseph Dehmer, National Science Foundation (NSF) Altaf Carim, Department of Energy (DOE)

		Ulrich Strom, NSF Daniel Friend, National Institute of Standards and Technology (via video)
4:15	Panel Discussion with Helium Suppliers	Phil Kornbluth, Matheson-TriGas Jane Hoffman, Praxair John Van Sloun, Air Products Carlos Nulman, Linde Global Helium
5:15		Final Discussions

Wednesday, June 25, 2008

Closed Session

SECOND MEETING
WASHINGTON, D.C.
AUGUST 21-22, 2008

Thursday, August 21, 2008

Closed Session

Open Session

11:00 am	Welcome to Guests	Chip Groat, *Co-Chair* Bob Richardson, *Co-Chair*
11:15	Recovery, Liquefaction, etc.	Jon Betts, Los Alamos National Laboratory
12.15 pm	Working Lunch	
12:45	NITEC LLC	Chuck Weinstein, NITEC
2:30	Break	
2:40	Presentation on National Security Issues	Sharon Murphy, Defense Energy Support Center

3:40	Presentation from a Nonrefining Supplier	Gary Ciesar, Air Liquide
4:05	Presentation from a Nonrefining Supplier	Phil Kornbluth, Matheson Tri-Gas
4:30	Presentation from Cliffside Partnership	Cliffside Partnership, Corporate Partner Representatives

Friday, August 22, 2008

Closed Session

THIRD MEETING
BECKMAN CENTER OF THE NATIONAL ACADEMIES
IRVINE, CALIFORNIA
NOVEMBER 3-5, 2008

Monday, November 3, 2008

Closed Session

Open Session

10:15 am	Greetings	Chip Groat, *Co-Chair* Bob Richardson, *Co-Chair*
10:20	Presentation from BLM	Leslie Theiss, BLM Field Manager
12:00 pm	Lunch	

Closed Session

Tuesday, November 4, 2008

Closed Session

Wednesday, November 5, 2008

Closed Session

FOURTH MEETING
BECKMAN CENTER OF THE NATIONAL ACADEMIES
IRVINE, CALIFORNIA
JANUARY 28-29, 2009

Wednesday, January 28, 2009

Closed Session

Thursday, January 29, 2009

Closed Session

Appendix D

The Economics of a Typical Recycling System

The economic analysis sketched here for basic research and engineering research applications is based on traceable data from at least one large facility and from a user survey conducted by the committee. For large systems, where liquid helium usage is at or above 50,000 liters (50 kL) per year, the costs scale approximately linearly to higher quantities primarily because the largest liquefiers now available are designed to handle about this level.

The one-time cost of installing such a liquefier in a research facility such as the National High Magnetic Field Laboratory, an NSF-funded example, is about $350,000. A fully integrated mechanical liquefier costs about $1,000,000, and cryogenic storage containers (dewars) cost about $70,000. These are nonrecurring costs. Overhead for an operator is about $100,000 per year. Maintenance, including the resupply of helium losses of 10 to 15 percent, is about $67,500 per year, and the cost of electricity is nearly $50,000 per year. The total capital outlay is thus $1,420,000, and operating costs are $217,500 per year. These expenses can be compared to the approximately $450,000 per year that it costs to simply buy and vent the same amount of liquid helium, using the average weighted cost to researchers of $9 per liter according to the survey conducted by committee member Moses Chan. This amounts to a saving of about $232,500 per 50 kL per year, giving a very favorable payback time of slightly over 6 years.

For smaller systems, several manufacturers sell small or medium-scale refrigeration systems know as lossless dewars, which are simply small stand-alone reliquifiers that are intended for a single low-temperature experimental station. For such systems, helium usage is reduced by an order of magnitude or more, with payback times that are hard to intimate precisely but that are probably near the 6-year payback time of large systems.

This presents an obvious strategy for U.S. government-funded basic research requiring liquid helium. Consider a U.S. government grant where helium expenses are explicitly known. When such a grant is funded, the recipient could be presented with three choices: (1) a helium nonconservation charge would be assessed against the grant, reducing it by the difference between the actual requested amount and what the grant helium costs would have been had a helium conservation system been in place; (2) a plus-up to the grant if helium conservation was not in place but was planned for implementation in the first year of the grant such that the plus-up would cover some large fraction of the implementation cost; or (3) a grantee already conserving helium might get the full nonconserved budget for the project for a year or two as an incentive.

Appendix E

Auction Types

According to Klemperer (2004) there are four basic types of auctions.[1]

- Ascending bid, or English auction, in which bidders (or the seller) bid higher and higher until the highest bid wins the good. Bids can be submitted by open outcry or signal. Increasingly, however, such auctions are being held electronically;
- The descending bid, or Dutch auction, in which the price is lowered until someone agrees to the price;
- The first price, sealed-bid auction, in which the buyers put in secret sealed bids and the highest bidder wins the good at the bid price; and
- The second price, sealed-bid auction, or Vickery auction, in which buyers put in sealed bids and the highest bidder wins the good at the second highest bid price.

An early theoretical result from auction theory is that under risk neutrality, independent values, free entry, and competitive bidding, the four mechanisms yield identical expected revenue and each bidder should bid his or her estimate of the true value for the object. If buyers are risk averse, expected revenues are higher for the ascending bid, but such a bid type attracts the fewest bidders. Furthermore, bidding may be used to signal colluding bidders. Thus in the helium market, where

[1]Paul Klemperer, *Auctions: Theory and Practice* (Princeton, N.J.: Princeton University Press, 2004).

there are few bidders and each has significant market power, the ascending open auction is likely not the best choice. Sealed-bid auctions tend to attract the most players. Since it is easier to collude in a second price, sealed-bid auction, a first-price, sealed-bid auction is the best choice for helium sales. Such sales, however, would require open access to the Cliffside reserves or to swaps, and this access would require monitoring by BLM or some other regulatory body.

Appendix F

Extraction Path Alternatives

To assess the various production strategies that might be considered for the Bush Dome Reservoir, it is necessary to consider the factors that impact the production potential for a single well as well as the impact of interactions between wells. Before assessing the various production strategies for the field, a short, simplified description of reservoir characteristics and well production is necessary, beginning with physical reservoir characteristics.

The ability to produce gas from a single well depends on physical, completion, and production factors, including the following:

- Physical characteristics of the reservoir rock in the field,
- Initial reservoir pressure,
- Composition of the gas and fluids in the reservoir rock,
- Number of wells and spacing of the wells within the field,
- Characteristics of the individual wells within the field once they are completed,
- Production paths chosen for the individual wells, and
- Enhancements to production, such as compression to change the pressure impact in a field.

The gas in place in a reservoir before production depends on the porosity (the percent of void space in the reservoir rock) and the physical dimensions of the reservoir (thickness, length, and width). These features, combined, determine the maximum amount of space available in the reservoir that can be occupied by gases. This volume is then reduced by water saturation—the percentage of the void filled by water.

The quantity of gas that can be produced depends on the permeability, or interconnectedness, of the reservoir rock, which determines how easily fluids can move through the reservoir, as well as on the initial reservoir pressure. Reservoir pressure generally increases with depth and is the pressure on the fluids within the pores of the reservoir. Initial pressure influences how quickly gas can initially be produced (all else equal).

The porosity, permeability, water saturation, and reservoir pressure will determine, in part, the amount of gas that can be produced from a single well drilled into a reservoir. However, the diameter of the pipe, the completion job chosen for the well, and the drilling path—the physical path along which the well is drilled—will also impact the primary production capability of the well. A complete assessment would require knowing the size of pipe used in the well, the number of perforations in the pipe, and any fracturing of the reservoir rock to enhance the ability of gas to flow to the pipe for production.

Total production from the well over time can also be impacted by the production path. Consider a well ready for initial production. The operator of the well could choose to produce the well at "absolute open flow." That is, it could allow the well to produce against the full force of the reservoir pressure. While this would generally result in high production at first, pressure might decline rapidly, producing too low a flow to maintain economic viability in later years. In other words, because there are minimum costs associated with operating a well, operating it at high rates initially will cause it to be very profitable at first, but fairly unprofitable soon after, even though significant helium remains.

An analogy can be made to the blowing up of a balloon. Assuming no reservoir damage from the aggressive production choice, releasing the gas from the reservoir would reduce the pressure in the reservoir, as would letting the air out of the balloon. If you blow the balloon up and then let the air escape unimpeded, the air will rush out but then decline over time as the pressure in the balloon declines. When there is no more air escaping there will still be some air inside the deflated balloon.

This well could also be produced more conservatively by letting the gas flow against a percentage of the available pressure, reducing initial production and also changing the pressure regime within the reservoir over time. For instance, in a second identical balloon, the air would be allowed to escape but with the throat of the balloon opened only partially. There would be different production and pressure paths. Production would be lower initially than from the first balloon, pressure would decline more gradually, and air would escape for a longer period of time.

The balloon example does not, however, reflect the complicated pressure gradients and barriers to flow that exist in actual reservoirs. In the balloon, the quantity of air left when the throat is wide open or only partially open might vary somewhat, but the variation probably is not significant. However, for the typical reservoir, the rate at which helium is removed can significantly affect how much helium remains when gas flow drops below levels at which it no longer is profitable to remove more gas. Typically, the structure of reservoirs is such that the greater the initial rate of production, the more gas remains when that unprofitability level is reached.

Gas fields do not generally consist of a single well. Instead, there are a number of wells within a producing field. The spacing of the wells will depend on the characteristics of the field. Highly permeable reservoir rock (all else equal) may not require as great a density of wells as less permeable reservoirs because fluids can flow more easily through the high-permeability reservoir and so can travel further to a well for production. Multiple wells can complicate production. Not only is an individual well impacted by the production choice for that well, but its production potential is also affected to the extent that production from other wells impacts pressure in its vicinity.

The production path chosen can also impact future potential by degrading the reservoir characteristics (usually under drawdown strategies that rely on higher pressure) and by changing the gas properties as fluids from the surrounding area move into the reservoir, commingling with the gas in place. Finally, production potential can be impacted by the addition of compression in the field, which impacts the pressure of the field and the field's future potential.

With these concepts in mind, various production strategies for Bush Dome Reservoir can be considered. Bush Dome Reservoir is slightly different because it is not a new field being considering for initial production. Rather, it has already been produced, and that production history impacts its current and future production capabilities, constraining the latter. However, the concepts presented in the preceding example apply at any point during the producing life of a field. In the end, determining the optimal production path depends on the objective of the producer.

MAXIMIZE WITHDRAWALS THROUGH 2015

Maximizing withdrawals is an objective that relates only to the physical resource and does not consider the costs of withdrawals relative to the value of the helium. To maximize withdrawals over a given time horizon, the production plan would have to take into account the field characteristics. Given that reservoir pressure declines with production, this objective would result in declining production over the time horizon. The initial production rates would be chosen to maximize the production potential of the pressure gradients in the reservoir over the time horizon, while considering the potential for reservoir degradation. This objective could include (or not) added compression and/or new wells.

The terminal time of 2015 adds a restriction to this production objective. Depending on the reservoir characteristics, a longer (or shorter) time horizon might result in higher total production. This, however, is a matter of reservoir engineering, not of economics.

MAXIMIZE TOTAL RECOVERY

Maximizing total recovery will result in the most conservative production plan of the ones presented. Again, this is not an economics-based objective, but a physical-based objective that may be consistent with treating the Bush Dome Reservoir as a strategic reserve. A strategic reserve would normally consider the value to a country of having access to helium. In this case it is the total quantity of helium that can be produced, regardless of time, that is important. This production objective (all else equal) would be most protective of the reservoir.

Given the more conservative production path, payback (if achievable) would be over a longer time horizon. This objective may also reduce the requirement for additional investment, because not as many additional wells may be needed to produce the helium as with the previous objectives. However, there is no guarantee of payback under this objective.

MAXIMIZE NET BENEFITS

Under the objective of maximum net benefits, the management plan for the field would be based on the simultaneous consideration of economic and reservoir factors. Gross benefits are gained from the production and use (sales) of the helium. Net benefits are gross benefits less costs of production and scarcity value. To maximize the benefits of the field, the production plan would look to maximize the net benefits over the optimal life of the field. However, such a plan would need to take into account that today's production choices impact the production choices available tomorrow (through changing pressure, reservoir degradation, etc.). Thus, the drawdown path would incorporate all of the economic and reservoir engineering information that would find the optimal trade-off between the marginal benefit from the production of another unit of helium today and the marginal cost of not leaving it for tomorrow plus the marginal damage to the reservoir from the production of one more unit today.

The committee believes that this last objective would be the most appropriate one for the Federal Helium Reserve. The efficiency of a production plan depends on its objective. If the objective is to maximize production over a time horizon or to maximize recovered gas, there are efficient paths to achieve these objectives. However, nothing will guarantee cost recovery. Maximizing net benefits will not guarantee maximizing recovery, nor will it guarantee breaking even. It does, however, provide a method to produce the helium that considers the value of helium in different time periods.

Appendix G

Executive Summary of *The Impact of Selling the Federal Helium Reserve* (the 2000 Report)

BACKGROUND

The Helium Privatization Act of 1996 (P.L. 104-273) directs the Department of the Interior to begin liquidating the U.S. Federal Helium Reserve by 2005 in a manner consistent with ''minimum market disruption" and at a price given by a formula specified in the act. It also mandates that the Department of the Interior "enter into appropriate arrangements with the National Academy of Sciences to study and report on whether such disposal of helium reserves will have a substantial adverse effect on U.S. scientific, technical, biomedical, or national security interests."

This report is the product of that mandate. To provide context, the committee has examined the helium market and the helium industry as a whole to determine how helium users would be affected under various scenarios for selling the reserve within the act's constraints.

The Federal Helium Reserve, the Bush Dome reservoir, and the Cliffside facility are mentioned throughout this report. It is important to recognize that they are distinct entities. The Federal Helium Reserve is the federally owned crude helium gas that currently resides in the Bush Dome reservoir. The Cliffside facility includes the storage facility on the Bush Dome reservoir and the associated buildings and pipeline.

NOTE: Reprinted from NRC, *The Impact of Selling the Federal Helium Reserve* (Washington, D.C.: National Academy Press, 2000).

IMPACT OF THE LEGISLATION

The helium community is currently enjoying an extended period of stability. Since the mid-1980s, there have been no drastic increases in the price of helium and no shortages of supply. The industry has consistently been emphasizing conservation. All the companies on the Bureau of Land Management (BLM) pipeline store their excess crude helium in the Bush Dome reservoir, and their net storage has led to the accumulation of a private stockpile of approximately 4 billion standard cubic feet (scf), equivalent to 110 million standard cubic meters

The price of helium will probably remain stable through at least 2010. The price established by the Helium Privatization Act for sales from the Federal Helium Reserve is approximately 25 percent above the current commercial price for crude helium. For this reason and because all helium refiners on the BLM pipeline have long-term take-or-pay contracts with producers of crude helium, it is highly unlikely that the refining industry will buy and use gas from the Federal Helium Reserve rather than from private stockpiles or cheaper commercial suppliers.

Once the private reserves are exhausted, however, refiners will have no realistic option other than to begin purchasing the crude available from the Federal Helium Reserve. (The only other source is more production, and production is driven by the demand for natural gas, not the demand for helium.) Nevertheless, under various plausible supply-demand scenarios, private industry will not need to purchase the entire Federal Helium Reserve to meet demand through 2020.

As the Hugoton-Panhandle gas fields are depleted and the Reserve is exploited, the price of crude helium will increase. However, because transportation and purification costs account for a large portion of the price of refined helium, an increase of 25 percent in the price of crude helium would probably increase the price of pure helium by only 8 to 10 percent.

Finding: Based on the information assembled for this report, the committee believes that the Helium Privatization Act of 1996 will not have a substantial impact on helium users.

FOLLOW-ON ACTIVITIES AND RECOMMENDATIONS

Although the committee does not believe the legislation will have a substantial impact over the next two decades, it recommends consideration of a number of research programs and follow-on studies. These will ensure that the legislation has no adverse long-term (beyond 2020) effects, and that sufficient supplies of helium will continue to be available after 2020 to satisfy the needs of known and potential users.

Reviews of the Helium Industry

First, the committee recommends that future reviews of the helium industry be commissioned by BLM either (1) in response to drastic increases or decreases in helium capacity or use or (2) regularly, every 5 or 10 years. The BLM should assist this review by improving its methods for tracking helium capacity and use. The following recommended improvements will help ensure the timely identification of important shifts in the industry:

- Develop and implement a consistent and credible taxonomy of helium uses.
- Develop and implement better methods for tracking the international helium market.
- Report helium reserves using the natural gas industry's classification scheme.

Study of the Depletion of the Reserve

Second, the committee recommends that the BLM study the adequacy of the Bush Dome reservoir as the reserves are depleted. Specific study tasks that should be considered include the following:

- Determine the optimal size of a federal stockpile of crude helium.
- Develop models of gas extraction at the Bush Dome reservoir to predict the helium content of future extracted gas.
- Determine whether the quantity of gas that remains in the Bush Dome reservoir will be adequate to meet future federal needs in the event of a temporary drop in private production.
- Reassess the pricing structure for the storage of helium at the Cliffside facility so that it more accurately reflects the value of the facility.

Research and Development

Finally, the committee recommends that the Department of the Interior conduct research and development to ensure the continued supply of helium into the future. Goals should include (1) new geological models and exploration technologies, (2) improved helium storage systems, and (3) enhanced technologies to conserve, recycle, and eventually replace helium. The following specific tasks should be considered:

- Determine the geological characteristics and processes that permit the formation of helium-rich gas fields and develop methodologies and databases to assist in the discovery of these fields.

- Identify potential sites for natural storage facilities to permit the establishment of new facilities near future major helium producers and to allow an increase in the storage and conservation capabilities of helium users.
- Develop economic models for the extraction and storage of joint-product, nonrenewable resources the production of one of which is dominated by supply and demand for the other.
- Incrementally improve the efficiency of technologies that currently depend on helium and develop alternative technologies that do not require helium