Testimony of Sophia E. Hayes

Professor of Chemistry, Washington University in St. Louis

St. Louis, MO 63130

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Research and Innovation to Address the Critical Materials Challenge

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Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research and innovation to address the critical materials challenge, and thank you for your continued strong support of physical sciences and energy research. I am Sophia Hayes, Professor of Chemistry at Washington University in St. Louis. I am a researcher who uses liquid helium extensively to both sustain instruments and to achieve very low cryogenic temperatures in my research.

Overview: helium touches nearly all lives

Helium is the second element on the periodic table (which I note because this is the International Year of the Periodic Table) and as a result, it is very, very small. Helium is so small that, unlike other gases, it will escape out of anything it is contained in, including the cylinders we temporarily store it in for immediate use and ultimately the Earth's atmosphere itself. Eventually, all the helium on earth will escape, and because we cannot make more of it on any realizable time-scale, it is the very definition of a non-renewable resource.

Helium is ubiquitous in our lives. It is an element of great importance for a large number of activities and products. It's used to cool magnetic resonance imaging (MRI) machines in medicine; to pressurize the rockets' fuel systems necessary to launch space missions; to manufacture the semiconductor chips, flat panel screens, and optical fibers that dominate our electronic "lives" and handheld devices; and as a critical element in red lasers. Helium is essential for each one of these processes. Helium use is of course also close to our hearts in the fun and fanciful uses for party balloons and the massive balloons in, for example, the Macy's Thanksgiving Day Parade.

Helium has two very special properties: 1) as a gas, it is used in balloons and lifting applications because it is lighter than air, and 2) when it is a liquid, it is the coldest substance on Earth, allowing us to cool down materials and use special “states of matter” – such as the superconducting state that is at the core of every magnetic resonance imaging machine or any other device that relies on extremely powerful magnets, like the particle colliders used by high energy physicists. In other words, without helium, these applications become closed off to us.

Research Community

I’m here to discuss the research community’s experiences and needs.

Helium is an element with many, many special properties – sometimes it will be useful to speak in analogies to make this exotic “chemical” more relatable.

Where helium has absolutely no substitute – is in cooling applications.

In practically every chemistry department in the U.S., there are instruments for “fingerprinting” molecules that require a constant supply of dozens of liters of liquid helium. These instruments are called nuclear magnetic resonance (NMR) machines – and these are close counterparts of the magnetic resonance imaging (MRI) machines used in medicine. (For ease of expressions, let’s call both “magnetic resonance.”)

These instruments *require* helium to operate; they cannot function without helium. Like the radiator in your car, these need to be filled with liquid helium as a kind of cooling fluid that is circulated around the components – that cooling fluid allows materials inside the instrument to achieve a superconducting state.

But liquid helium evaporates as it is being used and therefore must be replenished. If the liquid helium runs low, the components inside will stop superconducting, catastrophically generating incredible amounts of heat, potentially melting and destroying components on the inside of the instrument. For want of a dozen or so liters of liquid helium, capital equipment costing anywhere from $100K to $15M will be destroyed.

At my university, we have more than 2 dozen such instruments spread amongst 4 academic departments. These are essential for both conducting our cutting-edge experiments and training the next generation of scientists (chemists, physicists, materials engineers, and medical doctors).

Now, imagine there are 900 – 1000 academic departments in the U.S., with at least one, and often multiple magnetic resonance machines – all dependent on this sustaining chemical.

Moreover, this extends heavily into industry as well. Every pharmaceutical company, every research and development arm of oil and gas companies (such as Exxon Mobil, Chevron), and every chemical-producing company has one or more magnetic resonance machines. These instruments help researchers understand what they create in the lab when they combine chemicals to make new molecules. The advent of magnetic resonance in the 1960s and 1970s and its entry into industry was a game-changer. There is an analysis of the number of known or lab-synthesized chemicals tracked by decade (Chemical Abstracting Service, American Chemical Society), and there was explosive growth after the introduction of magnetic resonance, from hundreds of thousands of known chemicals in the 1960s to over 5 million chemicals by 1980 and tens of millions of chemicals today.

So magnetic resonance permeates all of chemistry. Some estimates put the total number of helium-using magnetic resonance magnets in the U.S. at 5000 of more, and this does not include medical instruments.

In physics, researchers search for exotic quantum states of matter by cooling experiments to extraordinarily low temperatures. It's so cold, we use a different temperature scale to make it easier for us to talk about. Temperatures from what's called "1 milli-Kelvin to 4 Kelvin" are regularly achieved. That's approximately -460 Fahrenheit to -452 Fahrenheit.

Finally, in medicine, nearly all hospitals depend on magnetic resonance imaging (MRI) instruments for life-saving medical diagnoses. MRIs can determine structures in soft tissue – that eludes detection by X-ray, or other scanning technologies, like positron emission tomography (PET) imaging.

Statement of the Problem

I hope I've made obvious the tremendous need for a reliable supply of (liquid) helium in the scientific research and medical diagnostic communities.

What we have faced in the past two decades is:

1) Steep price increases
2) Supply "shocks" – where helium could not be acquired in some cases at any price.

The origin of price increases comes from a market that is highly volatile. This is in an area of "resource economics" that is outside my area of expertise. I can simply comment that for researchers like myself who receive fixed budgets from the National Science Foundation, we cannot weather the tremendous price increases we have seen.

At my institution, the price for liquid helium has increased more than 400% from the start of my career – but the grants we receive have been flat, not accounting for such massive inflation in the price of a critical line-item in budgets. For researchers like myself, it means I have to choose between paying for helium or paying the salary to support a graduate student in getting a PhD. In my case, I have had to decommission magnets – reducing my lab's research capacity – simply because I couldn't afford to purchase the helium necessary to sustain them.

Even more critical than price is supply insecurity. Our magnetic resonance instruments need a regular supply of helium, as I mentioned earlier. A supply shock, lasting weeks or even a month, can be disastrous. Helium vendors simply tell us that we are being "allocated" only a fraction of what we order – or in some cases none at all. In the meantime, the reservoir on these instruments gets lower and lower by the day (from evaporation of the helium). My magnets need to be filled every 4 weeks, so a delay of even 2- or 3-weeks is a crisis. Importantly, if my supply is cut, it is likely that this is being felt regionally, meaning it's affecting magnetic resonance machines across universities, industries, and hospitals.

We have had several major supply shocks in my career – the most recent as a result of Qatar blockade – and multiple minor supply shocks. If you'll permit me to use another analogy, we are like cattle ranchers. We have a handful of magnets in our "herd" that will die during a drought. If they die, these magnets never come back. We can buy new ones, certainly, a massive capital expenditure, but know that we will face future droughts that could "kill off" the herd again.

Attempted Solutions

Given these supply shocks, forward-thinking civil servants and some of our professional scientific societies have tried to come to our community's rescue. It's important to mention these efforts, because there are people creatively fighting behind the scenes to find solutions.

Dr. Dan Finotello at the National Science Foundation crafted a program to use funds for a small number of helium recycling units for researchers within the Division of Materials Research program. Helium recyclers are large capital expenditures, but they substantially reduce the risk to those researchers who are fortunate enough to secure them. This equipment can dramatically reduce the amount of helium researchers need – the recycling efficiency can be 95% or higher – helping conserve grant funds and an irreplaceable resource.

Douglas Smith from the Defense Logistics Agency (DLA) and Dr. Mark Elsesser from the American Physical Society worked together to create a program for academic researchers that sourced helium through DLA. The American Chemical Society joined forces with this program, creating an APS-ACS Liquid Helium Purchasing Program. Quoting them: "the DLA, which is permitted to purchase liquid helium via the in-kind program on behalf of any federal grantee, serves as a "broker" for program enrollees. By combining its customers' needs, DLA substantially increases its purchasing power when negotiating contacts and price. Additionally, DLA offers a more reliable liquid helium procurement route — DLA has established relationships with multiple liquid helium suppliers and their customers are not tied to a single vendor."

For several years, DLA was able to provide program participants a reliable source of helium at lower prices than they could negotiate on their own, helping to protect smaller-scale university users who receive federal funding. Unfortunately, this program will be discontinued in January – in part due to turbulent helium market – showing how incredibly challenging this situation is.

Policy Recommendations

The APS-ACS program helped researchers reduce helium costs and mitigate pricing issues in the near-term. But our irreplaceable helium resources continue to be depleted and reducing our long-term use of helium is essential. With this in mind, we must enable as many academic researchers as possible to reduce their helium consumption without compromising their research programs.

As I mentioned previously, NSF's Division of Materials Research is helping a small number of researchers reduce their helium use – and save the government money over time – by providing funding for the purchase of helium recyclers. This program is successful, but far too modest to address the problems we are facing.

In my opinion, the NSF program should be looked at as a model, and Congress should ask federal agencies to support the wide-range adoption of helium recycling equipment. This will require agencies to invest in the capital equipment infrastructure necessary to make helium recycling commonplace. Unless funding is dedicated to help address the issue, the U.S. risks losing the research capacity responsible for many significant breakthroughs in areas such as medicine, national security and fundamental science.

Additionally, while outside the jurisdiction of this Committee, it is important to recognize that the U.S. Strategic Helium Reserve, which is scheduled for shutdown in fall 2021, is a central component of the domestic helium supply. Storage of an inventory of helium is critical for the health of our helium supply infrastructure. In the past, the Reserve has provided a vital bulwark against shocks to helium supply, ensuring that federal research and defense needs were insulated from disruption.

Given that we continue to experience helium supply disruptions, Congress should postpone the planned 2021 shutdown and sale/ privatization of the Strategic Helium Reserve, until the helium supply chain has been made more resilient to supply shocks and price spikes.

Thank you for the opportunity to testify. I and my colleagues will work with the Committee at any time now or in the future to help maintain the nation's security and economic competitiveness, by ensuring this vital resource is preserved.

Prof. Sophia E. Hayes is a Professor of Chemistry at Washington University in St. Louis, Missouri. Her research is centered on nuclear magnetic resonance, especially at very low temperatures, spanning topics in chemistry, materials science and condensed matter physics. Her research is wide-ranging, addressing new materials for carbon capture, metal oxide thin films, and quantum-mechanical phenomena in semiconductors. Washington University has long been a leader in the field of magnetic resonance, in multiple departments and disciplines, spanning physical sciences and medicine. Hayes is a co-author of the 2016 report "Responding to the U.S. Research Community's Liquid Helium Crisis" issued jointly by the American Physical Society, Materials Research Society, American Chemical Society (https://www.aps.org/policy/reports/popa-reports/upload/HeliumReport.pdf). She has taken an active role to raise awareness of helium supply issues internationally.
Prof. Hayes holds B.S. and Ph.D. degrees in chemistry from Univ. of California Berkeley, Univ. of California Santa Barbara, respectively. She was a Directorate Postdoctoral Fellow at Lawrence Livermore National Laboratory in the Division of Chemistry & Materials Science (jointly with U.C. Berkeley, Chemical Engineering), and she was an Alexander von Humboldt Fellow in Physics at Technical University of Dortmund, Germany.