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Mini Review

Recent Progress in the MRI Technologies designed to Address the Helium Shortage

Yong-Jihn Kim*

Depart of Physics, University of Puerto Rico, Mayaguez, PR 00681, Cutting Edge Superconductors, Mayaguez, PR 00680

***Corresponding author:** Yong-Jihn Kim, Depart of Physics, University of Puerto Rico, Mayaguez, PR 00681, Cutting Edge Superconductors, Mayaguez, PR 00680.

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Abstract

The recurring global helium shortage has increased concerns regarding the sustainability of conventional Magnetic Resonance Imaging (MRI) systems, which traditionally rely on liquid helium to cool the superconducting magnet. This review examines recent MRI technologies designed to reduce or eliminate this dependence. Developments in niobium-titanium (NbTi) systems have reduced helium inventories through improved cryogenic designs and conduction cooling, while alternative superconductors, including high-temperature superconductors and magnesium diboride (MgB_2), offer operation at higher temperatures without liquid helium. Emerging approaches extend toward eliminating magnet cooling altogether, including the patent-pending "No Cooling MRI" concept based on CES-2023. Collectively, these technologies show a potential progression from reducing helium consumption to eliminating both liquid helium and conventional cryogenic cooling.

Introduction

In 1908, Heike Kamerlingh Onnes successfully liquefied helium, followed by his discovery of superconductivity in mercury near 4.2 K in 1911 [1]. These discoveries ultimately contributed to modern MRI systems, which commonly use NbTi magnets to generate magnetic fields of 1.5 T and 3 T and beyond because of their reliable performance, established manufacturing infrastructure and low cost. However, NbTi must be maintained near 4 K, traditionally requiring between 1200 and 2000 liters of liquid helium. Global helium supply disruptions, rising costs, geopolitical instability, and competing demand have made this dependence increasingly problematic [2]. Recent MRI technologies have reduced helium requirements through improved cryocooler systems, including conduction cooling, with NbTi MRI systems requiring only approximately 0.7 L of liquid helium [3]. Alternative superconductors provide another pathway toward helium-free MRI. Magnesium diboride (MgB_2) can operate at higher temperatures using cryocoolers, with MgB_2-based MRI magnet capable of producing 0.5 – 1.0 T fields at approximately 20 K [4]. More recently, Cutting Edge Superconductors has proposed a patent-pending "No Cooling MRI" using CES-2023, which the company reports as a room-temperature, ambient-pressure superconductor [4].

Helium Shortage

Helium plays an essential role in conventional Magnetic Resonance Imaging (MRI) systems by maintaining superconducting magnets near 4 K. Although helium is abundant in the universe, economically recoverable supplies are limited, making it a valuable resource for medical, scientific, and industrial applications. Global helium supplies face recurring constraints from limited production, disruptions, geopolitical events, and increasing demand. These shortages have contributed to rising helium prices, as shown in Figure 1 [5].

This supply vulnerability is particularly important for MRI because conventional systems can require large quantities of liquid helium, typically from 1200 to 2000 liters, while a magnet quench can cause rapid helium loss. These concerns have increased interest in reducing MRI dependence on liquid helium.

Cryocoolers provide one alternative; however, cooling costs increase significantly near 4 K, as shown in Figure 2 [6]. Therefore, liquid helium remains practical for NbTi magnets operating near 4 K, while MgB2, with a critical temperature of 39 K, can operate near 20 K where cryocooler cooling is more practical [6].

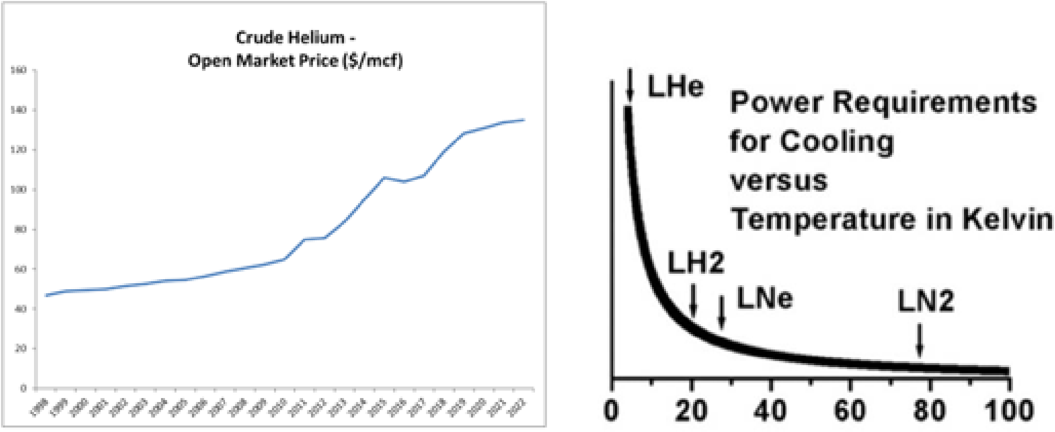

Figure 1 & 2: Helium price versus year [5] (left). Cooling expense as a function of operating temperature [6] (right).

These challenges have driven the development of reduced-helium NbTi magnets, MgB_2-based MRI, conduction-cooled systems with cryocoolers, and other technologies designed to reduce or eliminate liquid helium.

NbTi-Based MRI

NbTi remains the predominant superconducting material used in clinical MRI magnets, in conventional 1.5 T and 3 T systems. Its widespread adoption is largely attributed to its well-established manufacturing infrastructure, mechanical ductility, reliable superconducting properties, and extensive operational history. However, NbTi has a critical temperature of approximately 9 K and must generally be maintained near 4 K during MRI operation to provide a sufficient superconducting stability margin. Conventional NbTi MRI magnets have therefore relied on immersion in large reservoirs of liquid helium. Consequently, recent developments in NbTi-based MRI technology have focused not primarily on replacing NbTi, but on redesigning magnet cryogenic systems through reduced-helium reservoirs, improved thermal insulation, cryocooler-based recondensation, and sealed helium architectures. These developments have enabled substantial reductions in the helium inventory required for MRI operation while preserving the performance and manufacturing maturity associated with NbTi superconducting magnets.

High Tc Cuprate-based MRI

High-Temperature Superconducting (HTS) cuprates represent a promising alternative to conventional NbTi superconductors for reducing MRI dependence on liquid helium. Cuprate superconductors exhibit higher critical temperatures and can maintain substantial current densities under strong magnetic fields. These properties provide the possibility of operating MRI magnets at elevated cryogenic temperatures using cryocoolers or liquid nitrogen, substantially reducing or potentially eliminating liquid helium. However, HTS cuprates introduce engineering challenges related to magnetic field homogeneity and stability, conductor cost, quench protection, mechanical stresses, superconducting joints, and persistent-current operation. Breakthroughs in conductor manufacturing, and advances in magnet design, and cryogenic engineering are therefore required before widespread implementation in clinical MRI systems.

MgB_2-based MRI

Magnesium diboride (MgB_2) has the critical temperature of 39 K, enabling magnet designs based on cryocoolers and conduction cooling rather than large liquid-helium reservoirs. ASG Superconductors produces the cryogen-free 0.5 T MR Open Evo, which uses MgB_2 wire operating near 20 K with GM cryocoolers [7], as shown in Figure 3. Cutting Edge Superconductors, Inc. (CES) has developed patented MgB2 conductor technology (U.S. Patent 7,791,343), enabling cryogen-free 1.5 T MRI systems.

Conduction Cooling MRI

Conduction cooling provides an approach for reducing MRI dependence on liquid helium. Unlike conventional magnets immersed in a liquid-helium bath, conduction-cooled systems use mechanical cryocoolers and thermally conductive connections to maintain the superconducting magnet at its required operating temperature, as shown in Figure 4. This approach can substantially reduce or eliminate liquid helium requirements, but the price is higher than the conventional MRI, with some maintenance issues.

Figure 3 & 4: Cryogen-free 0.5T MR Open Evo [7] (left). Philips Ingenia 1.5T MRI [3] (right).

For NbTi magnets operating near 4 K, conduction cooling remains challenging because cryocooler efficiency decreases at lower temperatures. Higher-temperature superconductors can operate at elevated cryogenic temperatures, making conduction cooling more practical. Although challenges remain in thermal stability, heat management, and cryocooler performance, conduction cooling provides an important pathway toward reduced-helium and cryogen-free MRI systems (Figure 5).

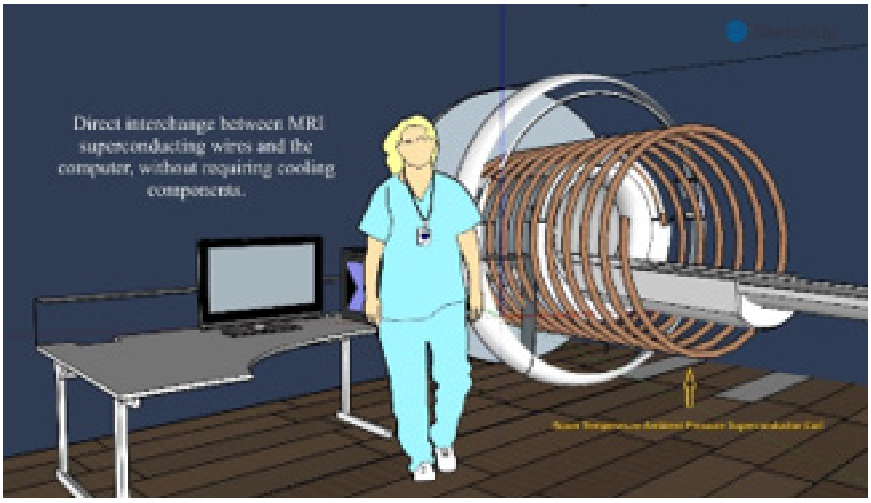

Figure 5: No Cooling MRI design from Cutting Edge Superconductors [4].

No Cooling MRI

A more recent approach to addressing helium dependence in MRI is the proposed "No Cooling MRI" being developed by Cutting Edge Superconductors (CES). The design is based on CES-2023, a room-temperature, ambient-pressure superconducting material.

Unlike NbTi and cryogen-free superconducting systems that still require low operating temperatures, CES-2023 is intended to operate at room temperature without cryogenic cooling. If successfully developed and implemented, this approach could eliminate the need for liquid helium and cryogenic cooling while reducing MRI system complexity and dependence on the global helium supply.

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Conflict of Interest

None.

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