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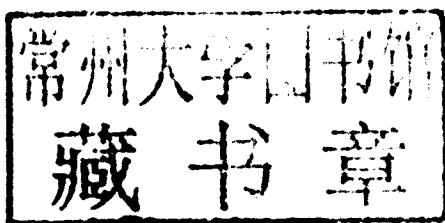
The Future of Helium as a Natural Resource

Edited by
William J. Nuttall, Richard H. Clarke
and Bartek A. Glowacki



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The Future of Helium as a Natural Resource

The purpose of this book is to inform the reader as to the future of helium: a most unusual substance, and a key natural resource with significant relevance for high technology. The frame of reference is international: helium is globalising.

Commercial helium is a by-product of the natural gas industry. The relationship of helium supply to natural gas is fundamental and has not been studied extensively in the past. The global natural gas industry is part-way through a profound change, with increasing emphasis on liquefied natural gas. This has major consequences for helium supply.

The authors turn their attention to helium supply and demand; most helium studies having previously been excessively focused on the supply side. Chapters study the potential impact of helium in a number of fields, including medical imaging and the nuclear industry, as well its influence in major national economies such as Russia and India.

William J. Nuttall is University Senior Lecturer in Technology Policy at the Judge Business School, University of Cambridge, UK.

Richard H. Clarke is a Cryogenic Process and Helium Specialist at Culham Centre for Fusion Energy, a UK-based research organisation developing fusion as a sustainable, long term energy source.

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Contributors

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Thomas W. Bradshaw is head of the Cryogenics and Magnetics Group at the Rutherford Appleton Laboratory. He completed his PhD at Lancaster University in 1979 on a nuclear adiabatic demagnetisation refrigerator for research on the properties of helium-3 at sub-mK temperatures. As a postdoctoral research assistant at Exeter University, he researched the transmission of phonons across solid-liquid helium interfaces, before joining the Rutherford Appleton Laboratory in 1983 to work on closed-cycle refrigerators in support of a range of satellite instruments. Recent projects include the building of a 4K cooler for Planck Explorer (launched May 2009, for which he is a co-investigator), proximity cryogenics for the ATLAS detector on the Large Hadron Collider and the further development of a range of miniature cryocoolers for long-life space applications. Current projects include the development of a long-life closed-cycle 2K cooler for ESA, the development of a superconducting magnet for the Muon Ionisation Cooling Experiment, development of superconducting undulators and the use of cryogenics for medical applications.

John W. Burgoyne leads the Magnet System Group in Oxford Instruments, responsible for the engineering, design and manufacture of superconducting magnet systems, of which a high proportion are custom-engineered to individual requirements. His technical background is in superconductivity and superconducting magnets, and he holds a BSc (Hons) in Applied Physics from the University of Strathclyde, and an MSc and PhD in Superconductivity and Cryogenics from the University of Southampton. Following his PhD, he performed postdoctoral work on high-temperature superconductors at Oxford University. Since joining Oxford Instruments in 1998, John has

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Zhiming Cai is currently working for AMEC UK Nuclear Limited as Senior Nuclear Safety Consultant. In 2005, Zhiming Cai entered the PhD programme after completing the MPhil course in Engineering for Sustainable Development at Cambridge University's Department of Engineering. His topic was the global helium market and resources, and the research was jointly sponsored by Linde-BOC Ltd and the UK Atomic Energy Authority. Before moving to Cambridge, he worked for seven years as a lecturer at an academic institution in China. In addition to an MPhil degree in Engineering for Sustainable Development from the University of Cambridge, he holds a Masters degree in Nuclear Reactor Engineering and Safety from Naval Engineering University at Wuhan City, China.

Roger Clare works for the Linde Group in its gas division, managing tonnage conceptual engineering for air separation plants in Asia Pacific. He has been providing specialist input for the helium resources project, examining the technology and cost of obtaining helium from air.

Richard H. Clarke is Cryogenics Specialist at CCFE (Culham Centre for Fusion Energy), a UK research organisation developing fusion as an alternative, long term, sustainable and clean energy source. He has developed a leading role in helium resource studies since joining CCFE as manager of the JET helium cryogenics plant. He was the industrial supervisor of Dr Zhiming Cai and is a Fellow of the Institution of Chemical Engineers. From 1995 to 2002 he was a principle heat exchanger specialist at the BOC group (now part of the Linde Group), designing and advising heat transfer solutions across the Group both in the UK and the US. While at the UK Atomic Energy Research Establishment, Harwell, from 1979–95 he negotiated and conducted contract compact heat exchanger (CHE) cryogenic, oil and gas research studies through HTFS (the Heat Transfer and Fluid Flow Service, now part of Aspen-tech) and he has many papers published on these topics.

Michael N. Cuthbert studied Chemical Physics at The University of Glasgow before his PhD at Imperial College in London. His thesis topic was "Dissipation in High Temperature Superconducting BiSSCO/Ag Tapes". Following this work on HTS materials using pulsed current transport techniques in low dc magnetic fields he went on to work on pulsed field susceptibility measurements on Low and High Temperature Superconductors as a PDRA at University of Bristol, UK. Since joining Oxford Instruments Cuthbert has worked in Japan and the US in various customer facing technical and commercial roles. He is currently Business Group Manager for the Ultra Low Temperature Group within the NanoScience Division of Oxford Instruments responsible

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Andrew Flower is the Principal Consultant at Flower LNG. As an independent consultant, he has advised clients in all parts of the world on issues such as strategy, markets, supply and demand, project structures and development, pricing, LNG shipping and contracts. He is a frequent speaker at major conferences and has had numerous articles published. He retired from BP in 2001, as Director of LNG, after 32 years of service, 22 of which were related to LNG. During that time he managed BP's LNG activities in Abu Dhabi, Nigeria, Qatar and Australia, and was involved in projects in Trinidad and Indonesia and feasibility studies for developments in Russia, Venezuela and Papua New Guinea. He has negotiated sales and purchase agreements with LNG buyers in Asia, Europe and the Americas.

Art Francis never retired from cryogenics. Throughout his career, until 1996, he was Helium Manager for Praxair Ltd USA, in charge of helium gas and liquid distribution. On formal retirement he set up his consultancy, trading as Cliffside Refiners, and continued to work for Praxair. He took charge of supplying liquid helium to the US research station at the South Pole for seven years, and helped to provide a continuous liquid supply lasting over the Antarctic winters from 2001. Following the USA 1996 Act to abandon the federal helium conservation programme, he wrote the 1998 manuscript for the book "Helium at the Crossroads", which was scheduled for publication as part of the OUP Cryogenic Monograph Series. In 1999 he was appointed manager of the Amarillo Liquid Helium Production Plant, and his book was never finished. However, the proposals in his manuscript, for an International Helium Management System, have been incorporated into this book *The Future of Helium*. He concerned, right to the end of his life, about the US Bureau of Land Management's having to sell off the federal conserved helium stock. He died in 2007, aged nearly 81.

Bartek A. Glowacki is Belvedere Professor and University Reader in Applied Superconductivity. He takes an interdisciplinary approach to applied superconductivity and advanced hydrogen-oxygen production technologies for fuel and cryogenic purposes as well as the development of advanced cryocoolers. He is strongly engaged in an academic and industrial partnership to develop advanced superconductors for numerous diverse applications. He is currently establishing a unique hydrogen laboratory at the University of Cambridge. As the only UK expert in applied superconducting conductors he was invited by the United Kingdom Atomic Energy Authority to represent them in the EFDA initiative to

design and develop MgB_2 and $\text{YBa}_2\text{Cu}_3\text{O}_7$ cables for the next DEMO fusion reactor. He is a World Energy Council member and European Energy Research Alliance representative. As Energy Expert for the Institute of Energy (Poland), he is responsible for policy governing the basic science programme.

Benjamin Hooker is an Accountancy and Finance graduate. He worked for Oceaneering International Inc., an oil service company in Aberdeen, before being transferred to Nigeria and Singapore, spending two years in each region. After returning to the UK, he was appointed Managing Director of Technotrak Limited, which designs, manufactures and retails safety equipment. Following the sale of Technotrak, he has consulted for a number of oil service companies and was until recently Director International of Newpoint Gas, a privately owned American manufacturer of modular gas treatment and processing skids responsible for the group's sales and marketing activities in Russia, FSU, UK, Europe and Africa. He is currently Managing Director of Eleuthera Capital Limited, a helium exploration and production company.

Nikolaos Kazantzis was educated at the Aristotle University of Thessaloniki (Greece), the University of Cambridge (UK) and the University of Michigan (USA), where he obtained his PhD in Chemical Engineering. Currently he is a Professor of Chemical Engineering at Worcester Polytechnic Institute (WPI), Worcester, Massachusetts, USA, an Associate Researcher at the Electricity Policy Research Group and Senior Associate at Hughes Hall, Cambridge University, Cambridge, UK, as well as a member of the Technical Advisory Committee of the MKOC Process Safety Center, Texas A&M University, College Station, Texas. He is the recipient of the Career Award of the US National Science Foundation (NSF) and his research interests lie in the areas of energy systems analysis, monitoring and control in the presence of complexity, systems science, system dynamics and energy policy analysis, process safety and chemical risk assessment.

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Trevor Miller took an Honours Degree in Physics at Bristol University before joining Gestetner UK in Production Engineering. His involvement with Cryogenics began in 1985 when he was with the Oerlikon Leybold Group. Since then he has worked closely with many varied technological applications but MRI and helium conservation have been consistent themes throughout. He feels privileged to have been involved since the early days of the technology, playing his part in helping to develop it as an essential tool available in hospitals and laboratories around the world. Trevor Miller is currently Managing Director of Sumitomo (SHI) Cryogenics Europe

Ltd, a part of Sumitomo Heavy Industries and global market leaders in cryogenic cooling equipment for helium conservation and similar applications.

William J. Nuttall is a Senior Lecturer in Technology Policy at the University of Cambridge, UK. In 1987 he won a Fulbright Pat-Graduate Student Award to the Massachusetts Institute of Technology, USA to study for a PhD in Physics. On returning to the UK he worked as a scientist in universities and then for the Institute of Physics in science policy. He joined the teaching faculty of Cambridge University in 2002. He holds a shared post between Judge Business School, where he is based, and Cambridge University Engineering Department. He has a leading role in the Electricity Policy Research Group and in the recently established Cambridge Nuclear Energy Centre. He has been researching issues relating to helium resources since 2005. He is a Fellow of Hughes Hall Cambridge.

Joseph B. Peterson is the Assistant Field Manager of Helium Resources at the Amarillo Field Office, Bureau of Land Management, Department of the Interior, located in Amarillo, Texas. He has nearly 30 years of federal service and has been involved in the helium industry for over 15 years. He has authored several scientific publications in technical journals and his office is responsible for the Annual Helium Minerals Commodity Summary and Annual Minerals Industry Survey Report on Helium. He is a graduate of the University of Alabama with a BSc in Chemical Engineering.

Benjamin Reinoehl is the Owner and Principal of RMW Solutions. In this role he consults for industrial gas companies, government and research users of industrial gases. RMW Solutions support helium projects and the collection of worldwide helium industry production data. Ben has over 50 years of experience in the industrial gas and steel industries. Particularly of interest is his experience with helium recovery, purification, liquefaction and marketing at Air Products and Chemicals, Inc.

Ralph Scurlock is Emeritus Professor of Cryogenic Engineering, and formerly Director of the Institute of Cryogenics at the University of Southampton, UK. In 1999, Ralph Scurlock was selected by the Cryogenic Engineering Conference (CEC) for the Samuel C. Collins Award for his work on cryogenic technology. He was the first person from outside the USA to be awarded this prestigious prize. He is the author of many papers and several books, including *Low Temperature Behaviour of Solids* (1965), *History and Origins of Cryogenics* (1994), "Low Loss Dewars and Tanks" (2004) and *Low Loss Storage and Handling of Cryogenic Liquids. The Application of Cryogenic Fluid Dynamics* (2007).

Bo Sears has over 17 years of oil and gas exploration experience. Bo has been instrumental in the development of key helium exploration projects across North America. His experience in the exploration arts (geology, geochemis-

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Richard Stainsby is currently the Coordinator of the European Commission's gas-cooled fast reactor (GCFR) project and is the EC's Representative on the Generation IV GFR System Steering Committee. Richard, together with a number of his AMEC colleagues, act as consultants to the South African and United States nuclear regulators on the licensing of high-temperature reactors (HTRs) in those two countries. They are also active members of the European HTR network and the Materials and Components Sub-Project Leader within the EC's RAPHAEL project.

Adrian Thomas graduated in Physics from The University of Birmingham in 1985. He subsequently studied Reactor Physics before working for the UK Atomic Energy Authority. In 1988 he moved to Oxford Magnet Technology (now Siemens Magnet Technology), where for 20 years he has been responsible for the design of some of the most commercially successful superconducting magnets for use in Magnetic Resonance Imaging (MRI) systems.

Acronyms and abbreviations

(RE)BCO	HTS magnet material similar to YBCO where RE=yttrium, gadolinium, samarium ... (rare earths)
^3He	Rarer isotope of helium (with one neutron), mostly primordial (Big Bang) in origin
^4He	Common isotope of helium (with two neutrons), mostly from radioactive decay of U and Th
A	Current (amps)
AC	Alternating current
AFM	Atomic force microscope
AGR	Advanced gas-cooled (nuclear fission) reactor
Al	Aluminium
APCI	Air Products and Chemicals Inc., Allentown, PA, USA (industrial gases and equipment, chemicals and processes)
Ar	Argon
ArcaTech	ArcaTech 100 market index (NYSE) (US listed companies engaged in computer hardware, software, semiconductors, telecommunications, electronics, aerospace and defence, health care equipment and biotechnology)
As	Arsenic
ASU	Air separation unit (industrial-scale cryogenic separation of components of air)
B	Magnetic induction (Tesla)
B//c	Where magnetic induction, B, is applied to a superconductor parallel to the crystallographic axis c
Ba	Barium
barg	Bar, gauge pressure (1 barg=29.2 psia); bara, bar absolute
BBC	British Broadcasting Corporation, London
B_{c2}	Upper critical magnetic induction (Tesla)
Bcf	Billion (10^9) (standard) cubic feet
Bcm	Billion (10^9) cubic metres
BEA	Banque Extérieure d'Algérie, Algiers
Bi	Bismuth
Bi-2212	$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ (an HTS superconductor)

Bi-2223	(Bi,Pb) ₂ Sr ₂ Ca ₂ Cu ₃ O _x (an HTS superconductor)
B _{irr}	Irreversibility field (magnetic) at which superconductor does not show hysteresis
BLM	US Bureau of Land Management, administrative body that manages US federal helium reserves
BOC	BOC Group Plc, now part of the Linde Group, Munich, Germany (industrial gases and services)
BOM	US Bureau of Mines, agency responsible for US helium reserves before the Bureau of Land Management
BRIC	Acronym for Brazil, Russia, India, China, a grouping of emerging economies
B-T	Magnetic induction – temperature
Btu	British thermal unit (1,055 joules)
°C	Degrees Celsius
C	Carbon
C	Specific heat capacity (at constant pressure or volume)
Ca	Calcium
CAGR	Compound annual growth rate
CBM	Coalbed methane
CCFE	Culham Centre for Fusion Energy, Culham Science Centre, Abingdon, UK
CCR	Closed-cycle refrigerator
CD	Current drive, forms of additional heating used in MCF fusion to raise the plasma temperature
CERN	European Organization for Nuclear Research, Geneva
CH ₄	Methane (the major component of natural gas)
CHEU	Crude helium enrichment unit, BLM's process plant that enhances helium recovery (Cliffside, TX, USA)
CHP	Combined heat and power, where more efficient utilisation is made of a primary energy source
CICC	Cable-in-conduit conductor, an arrangement of superconductor and normal conductors for high B uses
CISFHR	Committee (of NAS) on the impact of selling the federal helium reserves
cm	Centimetre
CNPC	China National Petroleum Corporation, Beijing, PR China
CO ₂	Carbon dioxide
CPI	Consumer price index
CT	Computed tomography, a medical imaging technique
Cu	Copper
D	Deuterium, or ² H, a naturally occurring heavy form of hydrogen (two neutrons)
DC	Direct current
DCFC	Direct carbon fuel cell
DCS	Distributed control system (process and power plants)

DEMO	Generic name of the first power-generating demonstration (MCF fusion) reactor
DNA	Deoxyribonucleic acid
DoI	US Department of the Interior, Washington, DC (an agency mandated to protect US natural resources and heritage)
DR	Dilution refrigerator (a “wet”, sub-1 K refrigerator containing a ^3He - ^4He mixture)
EIA	Energy Information Administration, Washington, DC (a US energy statistics/information centre)
EOR	Enhanced oil recovery (methods for increasing recovery of oil from a field)
Er	Erbium
Er_3Ni	Erbium-nickel alloy (has unusually high specific heat at LHe temperatures)
EU	European Union
FC	Fuel cell, chemical–electric energy converter
FCL	Fault current limiter, a device that prevents excessive current from flowing in a network or grid
Fe	Iron
FID	Final investment decision (in the context of LNG facilities)
FIR	Far infrared (spectroscopy)
FIS	Front Islamique du Salut (Islamic Salvation Front, Algeria)
FLIR	Forward-looking infrared (as in FLIR thermographic cameras)
FNL	Front de Libération Nationale (National Liberation Front, Algeria)
FSRU	Floating storage and regasification unit (for LNG)
FW	Flywheel, as used in energy storage devices (including superconducting versions)
G	Gas field size MMscf (or field production rate MMscf/day)
G	Giga (billion, 10^9)
GAN	Gaseous nitrogen
GATE	Major LNG import terminal in Rotterdam, the Netherlands (GATE= Gas Access To Europe)
GCFR	European gas-cooled fast (nuclear fission) reactor project
Gd	Gadolinium
GdBCO	Gadolinium-barium-copper-oxygen magnet (note: B means Ba and C means Cu in this context)
GDC	Gas Developments Corporation, Chicago, IL, USA
GDP	Gross domestic product
Ge	Germanium
GE	General Electric Company (a multinational energy, technology, consumer goods and finance conglomerate), Fairfield, CT, USA
GFR	Gas-cooled fast (nuclear fission) reactor
G-L	Gas-liquid (as in gas-liquid separator vessel)
GL1K, etc.	See GL1Z, etc. (LNG trains at Arzew, Algeria)
GL1Z, etc.	LNG process train (sub-unit) at Arzew, Algeria