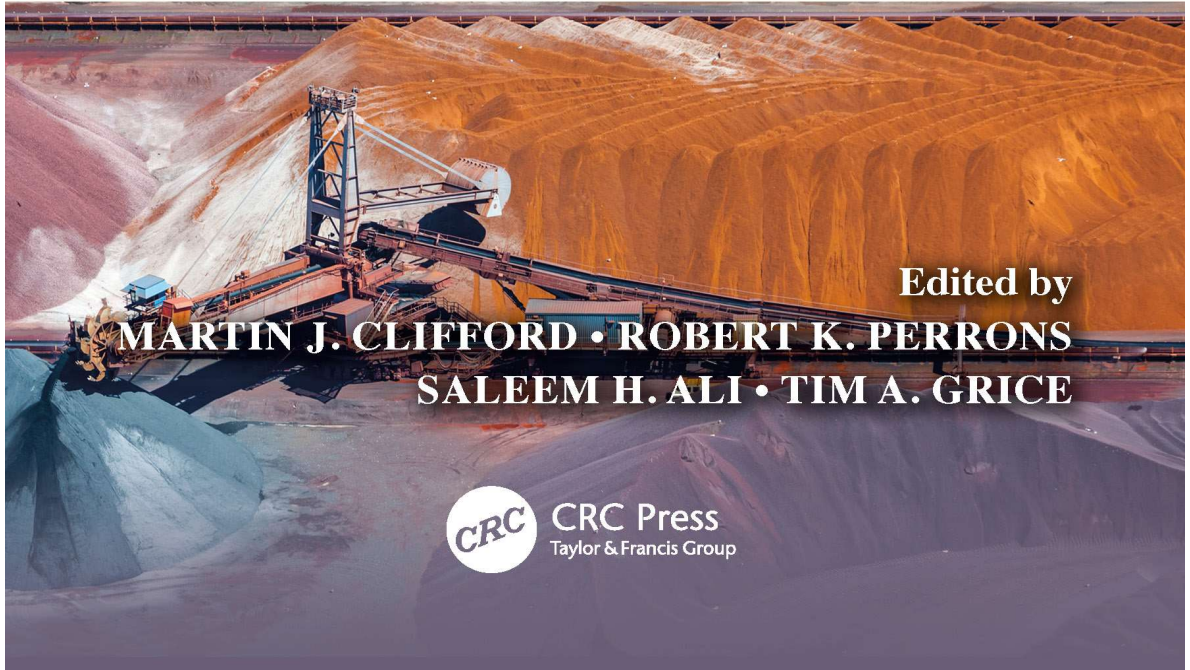


# EXTRACTING INNOVATIONS

Mining, Energy, and Technological  
Change in the Digital Age



Edited by  
**MARTIN J. CLIFFORD • ROBERT K. PERRONS**  
**SALEEM H. ALI • TIM A. GRICE**

 **CRC Press**  
Taylor & Francis Group

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## *Editors*

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**Martin J. Clifford** is a postdoctoral researcher in Energy and Environmental Policy at the Department of Geography, University of Delaware, Newark, Delaware. His work focuses on the socioeconomic and environmental dynamics of large and small-scale extractive industries, particularly in lower income countries. Much of his empirical work in this regard took place in Ghana and Guyana. This ties into his broader interests in international development and sustainable natural resource management. Much of his recent scholarship has focused on the Minamata Convention on mercury reduction and its impact on the gold mining sector. He has also completed a study on pathways for socioecological resilience in small-island developing states with extractive resources, focusing on the island nation of Nauru. This work was supported by the Pavetta Foundation. He earned a PhD and MSc in International Development from the University of Reading, Reading, England and the University of Manchester, Manchester, England, respectively.



Prior to joining the Queensland University of Technology (QUT) in Australia as an associate professor in 2011, **Robert K. Perrons** worked in a wide variety of roles and locations for Shell International's Exploration and Production division. He started his career in Shell's Strategy and Economics team in 1997, and then worked for several years as a production engineer in the company's overseas operations (offshore and onshore). He left Shell for 3 years to work as an Industrial Research Fellow at the University of Cambridge in the United Kingdom, and then rejoined Shell again in 2004 to become the company's Executive Coordinator of Research and Development. He earned a Bachelor of Engineering in mechanical engineering from McMaster University in Canada, a Master's degree in Technology and Policy from the Massachusetts Institute of Technology (MIT), and a PhD in engineering from the University of Cambridge, where he was a Gates Cambridge Scholar. He is a Fellow of the UK's Institution of Mechanical Engineers (IMechE) and Engineers Australia, and is chartered as a professional engineer (Eur. Ing.)

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**Saleem H. Ali** holds the Blue and Gold Distinguished Professorship in Energy and the Environment at the University of Delaware, Newark, Delaware where he also directs the Gemstones and Sustainable Development Knowledge Hub, supported by the Tiffany & Co. Foundation. He is also a Senior Fellow at Columbia University's Center on Sustainable Investment. Professor Ali has held the Chair in Sustainable Resources Development at the University of Queensland's Sustainable Minerals Institute in Brisbane, Australia (where he retains professorial affiliation). His books include *Treasures of the Earth: Need, Greed and a Sustainable Future* (Yale University Press); *Environmental Diplomacy* (with Lawrence Susskind, Oxford University Press) and *Mining, the Environment and Indigenous Development Conflicts* (University of Arizona Press). Corporate and government experience includes employment in General Electric's Technical Leadership Program; a Baker Foundation Fellowship at Harvard Business School and a Research Internship at the UK House of Commons. He is a member of the United Nations International Resource Panel, was chosen as a Young Global Leader by the World Economic Forum in 2011, and received an Emerging Explorer award from the National Geographic Society in 2010. He earned his doctorate in Environmental Planning from Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts; a Master's degree in Environmental Studies from Yale University, New Haven, Connecticut; and a Bachelor's degree in Chemistry from Tufts University, Boston, Massachusetts (*summa cum laude*).



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# *Introduction—Extracting Innovations*

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Martin J. Clifford and Saleem H. Ali

The key challenge is not so much globalization. It is actually, what I call the Fourth Industrial Revolution. Because it's technology which creates the major changes in our daily lives. It's technology that creates the fears. What we want to do is make the world much more aware. On the one hand is the opportunity of the new technology but on the other hand is the risks and dangers we encounter.

—Klaus Schwab

Extraction of mineral resources marks temporal milestones in human civilization. From the Stone Age to the Bronze and Iron Ages, we have developed as a species through a remarkable ability to innovate in our methods of extracting the most useful mined elements. Fossil fuels also have catalyzed innovation through the advent of the Industrial Revolution from coal to oil to natural gas harkening back to similar subterranean innovations that also characterized other earthen resources.

In this book we consider the most contemporary innovations that are now propelling the extractive industries forward while also creating new environmental and social challenges. Since the extractive industries are considered nonrenewable on human time scales in terms of their extraction from the Earth's crust, their extraction is becoming more technically arduous. Economic geologists often have been reluctant to use the term "non-renewable" in this context because of the relentless ability of technologies to extract more inaccessible ores. Yet, the specter of exercising innovations on conventional geological ore bodies is narrowing and new frontiers of resource bases are being explored from deep sea beds to asteroid deposits.

We consider such new frontiers of mineral extraction and the innovations they require, but are most concerned about the ways in which industry is having to adapt to imminent structural changes in our economic and social systems. The founder of the World Economic Forum, Klaus Schwab, heralded this as the dawn of the "Fourth Industrial Revolution," characterized by a highly networked digital society, and carrying important implications for the extractive industries. This has led to opportunities for industry to save costs and reduce occupational risk through automation and remote operations. At the same time, communities have demanded greater environmental protection from the negative impacts of mining which has necessitated a range of ecological innovations.

The socioecological fabric of innovation in the extractive industries is thus considered in this volume through an integrative approach that brings together engineers, natural scientists, and social scientists. The book had its genesis in a symposium that was organized by coeditor Robert K. Perrons at the Queensland University of Technology in Brisbane, Australia, in partnership with the Oil, Gas, and Mining Club of the Massachusetts Institute of Technology. This collaborative effort between two major research universities alongside numerous external participants galvanized interest in such a volume from practitioners as well. The result is this book which brings together academic voices in concert with practitioners to give an empirically grounded and realistic evaluation of the innovations in this sector.

The goal of this book is also to consider the limits of innovation in various arenas. With concerns such as climate change and tailings waste management perennially on the horizon, there is also a need to consider broader paradigm shifts in the sector in terms of reuse and recycling of materials and a gradual movement toward what is being termed a “circular economy.” We hope that this book will pave the way toward such a long-term trajectory for more efficient and sustainable resource usage.

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## **Book Structure**

This book is divided into three sections. [Section I](#) of the book provides more contextual depth to the impetus for the (thus far presumed) need for greater integration of technological innovation in the resources sector and the processes and organizational designs that might facilitate this. It opens with an analysis by John Steen, Sam Macaulay, Nadja Kunz, and John Jackson on the “innovation ecosystem” in mining ([Chapter 1](#)). The authors weave a contextual examination of the nature, drivers, trends, and challenges of innovation within the sector. Lessons that can be drawn from the adoption of innovation in other, comparative industries, namely agriculture and aerospace, are cited as encouraging examples for the mining industry to follow suit. Engagingly, the narrative here is interspersed with quotes derived from interviews with mining managers and executives gathered over the course of 2 years.

Following this, Kane Usher and Ian Dover offer their take on the coexistent “barriers and imperatives” to innovation in the mining sector ([Chapter 2](#)). They reassert the contradictory tale outlined in the previous chapter of global conditions necessitating change but the specific nature of mining as an activity making this inherently challenging. This, they argue, results in a propensity to adopt and preserve low risk methods that “work” rather than being involved in the “creative destructionist” arms race that has characterized the manufacturing, electronics, and software sectors. They propose that effective leadership from senior levels in mining organizations can be used

to drive companies through “three horizons of growth” and into a more innovation-friendly environment.

Chapter 3 draws the same line of enquiry for the oil and gas sector, which has traditionally had a reputation for being slow to develop and adopt innovation. One of the editors of this book, Robert K. Perrons, offers an analysis of his survey, conducted in collaboration with the Society of Petroleum Engineers that sought to gather insights directly from those involved in the industry into exactly how innovations happen in their sector and which networks prove most valuable in this regard. While the results might make gloomy reading for academic and independent research bodies, they do confirm the trend noted at several points within this book of a shift toward externally produced innovation.

Indeed, relying upon a closed system has had very real impacts for the Mexican hydrocarbon sector, as Victor Gerardo Ortiz Gallardo outlines in his brief appraisal that constitutes the first of the book’s shorter “vignette” contributions (Chapter 4). Due to total monopoly held by the state-owned oil company, PEMEX, his organization, the Mexican Petroleum Institute, and a small team of other suppliers, has worked solely with one entity for many years. He highlights how this has slowed progress in technological developments, despite some interesting projects.

In the case of Australia, the government has, in fact, set out to ensure that its most important economic contributor is “future-proofed” with the establishment of the National Energy Resources Australia (NERA), a not-for-profit with a mandate to grow collaboration and innovation in the country’s energy resources industry. In Chapter 5, Miranda Taylor, NERA’s chief executive officer, briefly highlights the context under which the organization came about, their identified goals, and the approaches to ensuring continued competitiveness and innovation in the coming decades.

Closing off the first section and setting the scene for the next is John McGagh, former Head of Innovation at Rio Tinto, who gives his viewpoint on what makes “now the time” for kickstarting a new wave of advances in the mining sector and what represents the most promising areas for technological improvements (Chapter 6). Specifically, he picks out effective use of “big data,” much wider use of automated systems, and the need for a renewed look at process methods as fruitful areas for future developments.

Section II of the volume looks at principles, practicalities, and potential of such developments in action, highlighting how the use of technological innovation is beginning to permeate the extractive industries in a myriad of ways. An engaging way to start this collection is through Jonathon Ralston, Craig James, and David Hainsworth’s longer term overview of the emergence and evolution of digital technologies in mining (Chapter 7). They use the example of longwall coal operations, stretching back 60 years and working through to the modern era. They round the chapter off by highlighting emerging areas of technological innovation as well as important areas for future consideration and development of the digital mining ecosystem.

Brian J. Evans, Head of the Petroleum Engineering Department at Curtin University in Perth, Australia, also takes a broad view of what the implementation of technology might look like on a pragmatic level and some of the (often less considered) knock-on effects for a daily operation in [Chapter 8](#). He considers the example of an operating room for a liquefied natural gas (LNG) gas train, and what the full integration of data sources, analytics, and automation might look like for an individual using these systems.

Moving to more specific areas of focus and research, coauthors Robert K. Perrons and Derek McAuley provide another valuable contribution on this topic in [Chapter 9](#), which explains how the “big data” revolution will probably unfold differently in the mining sector than it has elsewhere throughout the marketplace. The authors point to important differences in the costs associated with acquiring large volumes of data in a mining environment, and make the case for a more focused data collection and processing strategy than what is being evangelized these days by many vendors and consultants in the data analytics domain.

And there are signs that the oil & gas industry is also refining and re-shaping its data management philosophies in the face of “big data,” too. In [Chapter 10](#), Richard Mohan David explores how companies in that sector are more effectively using data and technology as parts of the evolution of “digital oilfield” technologies. As well as pointing out some of the more prominent “strategic initiatives” for integrating next generation technologies, he narrows in on what he terms “data driven technologies,” which are beginning to harness the depths of previously underutilized data, as being particularly promising.

[Chapters 11](#) and [12](#) provide examples of just this type of data use in action. Justin Montgomery and Francis O’Sullivan’s modeling of the productivity of unconventional oil and gas wells, something which has proven to be extremely unreliable, is based upon predictive analytics. This form of analytics is reliant upon capacity for data mining, modeling, machine learning, and artificial intelligence that previously were not technologically possible and have found increasing weight in natural resource research. Ali Soofastaei, Peter Knights, and Mehmet Kizil also employ data analytics in their proposed model to optimize the fuel efficiency of haulage trucks. Using artificial neural network modeling and genetic algorithms, which again rely on computing reams of data and running a huge number of complex functions, they arrive at an extremely high agreement between (their) modeled and observed fuel consumption. With material haulage consuming a significant proportion of energy consumption at mining sites, this proposed model has significant potential to improve efficiencies in active mines or before production even begins. The wider point of these two studies, of course, is demonstrating that the large amount of data collected daily by energy companies can be put to effective use with appropriate harnessing of increasingly advanced technological techniques.

As is highlighted in many of the overviews of the sector, in the modern context of the industry, the largest percentage of innovation arises not in the

research and development departments of companies, but from firms that supply them with products and services. P.J. Hollenbeck of ARANZ Geo, a technology provider for the mining, energy, and environmental industries, provides us with an archetypal example of this in practice in [Chapter 13](#). He takes us through the development and numerous uses of the company's Leapfrog Aspect Viewer, a geological modeling process that uses augmented reality to allow the user to visualize the model and physical space simultaneously using the camera software on a mobile device. This is a perfect illustration of the innovative work that companies that supply the industry are driving through. Encouragingly, extractive companies are increasingly alert to the potential of collaboration. Energistics Consortium, a not-for-profit industry consortium working with extractive firms and suppliers, aims to bridge this process in [Chapter 14](#). They provide standards, protocols, and tools not only to corporations but also to associated technology companies, with the aim of ensuring a consistency and interconnectedness across the board. In a brief vignette, they review the context behind and effectiveness of their work.

A total alternative to attempting to streamline efficiency and boost productivity in known energy resources, however, is to seek out and exploit entirely new frontiers, something that underpins the emerging deep-water and embryonic off-Earth mining industries, which round off our [second section](#). Again, and centrally with the theme of this book, moving such ideas toward reality has been the result of substantial technological progress over recent decades. Lindsey Harris of the University of Hawaii summarizes the technical advances and the social, environmental, and regulatory dynamics surrounding the growing discussion of the deep-water mining industry in [Chapter 15](#). Then, Serkam Saydam, who has collaborated with NASA and the Kennedy Space Center, reviews the literature relating to the prospects of mining on asteroids, the Moon, and Mars and summarizes the major remaining technological challenges that need to be overcome for the industry to realistically come into existence in [Chapter 16](#).

In the [third section](#) of the book, elements of social responsibility and environmental stewardship that intersect with innovation and technological adaptation are introduced. As Sharon Flynn puts across in her responses at the outset of this portion of the volume ([Chapter 17](#)), the seminal World Bank report into the social and environmental performance of the extractive industries and the consequent introduction of Performance Standards by the International Finance Corporation (IFC) have, commendably, "rocked the boat," heralding a shift in corporate approaches from well-critiqued standard offerings toward more collaborative, sustainable, and socially embedded strategies. As she goes on to emphasize, a rapid adoption of such approaches will be essential as future mining operations are likely to increasingly have to look toward areas of higher population density or ecological diversity in the search for new ore bodies.

The proliferation of public-private partnerships (PPPs) between companies, host governments, and local communities are a prominent example of the "new breed" of social responsibility arrangements. The work of companies like ExxonMobil, whose LNG project in Papua New Guinea is the subject



of John Moore, Andry Nowosiwsky, Valentina Kaman, and Gary Krieger's [Chapter 18](#), seeks to go beyond traditional Corporate Social Responsibility (CSR) approaches to create "shared value" and a platform for more impacting and lasting social integrity. The authors provide an engaging and in-depth discussion of the context, critiques, and considerations regarding PPPs, and the company's experience in implementing such a partnership. It is a highly informative case study for academics and (governmental and corporate) policymakers alike.

A likely and seemingly emerging trend is for these partnerships to stretch across sectors, as evidenced by the study outlined in [Chapter 19](#) by Tim Grice and Saleem Ali, two of the volume's editors. This initiative to extend mobile banking and financial inclusion in Papua New Guinea resource regions is anticipated to involve financial regulators, banks, and telephone companies alongside extractive operators and host communities in a "multistakeholder working group." It will be extremely interesting to see how these types of schemes develop.

Bruce Harvey's comments on the emerging field of "local level agreements" (LLAs) in [Chapter 20](#) carries a similar sentiment to the two preceding chapters. The central tenet of these agreements is the sharing of benefits that result from resource exploitation between companies and land-connected communities. By highlighting the "ideal" content and processes in establishing of such agreements, the author attempts to emphasize this approach as an innovative way of ensuring much more direct, collaborative, and long-standing interaction between companies and host communities than can be said of pre-existing CSR initiatives.

If the subject of PPPs and LLAs deal with proactive social engagement, there are also significant challenges and substantial scope for improvement in the way companies react to social criticism and incidents. For example, previous approaches for dealing with social incidents (e.g., protests, strikes) involving resource developers have come under scrutiny. Simultaneously, there is also increasing external demand to deliver technically rigorous social due diligence in increasingly demanding circumstances, which many companies have struggled with. Deanna Kemp, John R. Owen and Jill Harris examine in [Chapter 21](#) how social science methods and models, which have traditionally been kept "outside the fence" by many mining companies, could provide a much more nuanced and, as a result, informed understanding and mitigation toward dealing with social incidents and helping to stop them reoccurring.

Colette Einfeld, Sara Bice, and Chen Li's [Chapter 22](#) on the challenges posed by social media for extractive industries' community relations practices is extremely interesting for its focus on less orthodoxly considered elements in modern Public Relations (PR), especially among industries with more traditional approaches, like in mining, oil, and gas. Using an analysis of Twitter in relation to proposed or existing coal seam gas ("fracking") operations in Australia, the authors point to how the rapid and geographically untethered spread of multiple streams of information to a huge disparate

audience has given birth to new forms of “concerned communities” and activism. Despite not existing in an electronic dimension, these streams can have very real reputational and operational impacts and require a new, as of yet unconsolidated, approach by companies toward protecting their social license to operate.

Moving on to environmental innovations, in [Chapter 23](#), Philip N. Nkrumah, Guillaume Echevarria, Peter D. Erskine, and Anthony van der Ent present the interesting case of phytomining, in which metallophytic plant species, especially those that are “hyperaccumulators,” are used to draw metals from the ground which are then harvested from their biomass. This interesting idea could be used as a method to rehabilitate former mining lands by removing elevated metallic compounds in an economic and ecological fashion. It can also be used, the authors suggest, as a mining method on scattered, less economically viable deposits, possibly as smaller, “agro-mining” operations. Using the example of nickel accumulation, the authors outline suitable environs, selection of appropriate species, processing methods, and the potential economics of the practice.

Interestingly, the ecologically friendly methods outlined here may owe a partial debt to research carried out at the Eden Project, an equally conceptual and practical location in a former clay mine, as described by Saleem Ali in [Chapter 24](#). The Eden Project is not merely a tourist attraction but a pragmatic exercise in post-mining rehabilitation, centered around an ethos of renewability. Part of this project is restoration research, including identifying species suitable for the phytomining methods, mentioned by Nkrumah and his coauthors, in the facility’s greenhouses. This was in addition to stabilizing and construction of the site itself, using the pit and thousands of tons of topsoil, in both a feat of engineering and a utopian ideal of what can be done with former mining sites.

Finally, Jonathan Stacey, Yolande Kyngdon-McKay, and Estelle Levin-Nally introduce a method for an innovative rehabilitation approach tailored for the artisanal and small-scale mining (ASM) sector in [Chapter 25](#). As a sector that is largely unregulated and informal, driven by poverty, and has proven resistant to change, this approach is a tough task. It is also a worthy one, particularly with ASM; the social and environmental impacts are very clearly felt by local communities, and the price of permanently debilitating formerly useful land is a heavy price to pay for the (typically) short-term gains of extracting what is underneath. The authors introduce a detailed, locally appropriate, and potentially replicable framework for rehabilitation in this context, the Frugal Rehabilitation Methodology, implemented in Mongolia. This approach is a very welcome addition to the ASM literature, which often attempts to quantify and reduce environmental impacts during operations, but has thus far had very little to say on what should be done afterwards.

The “Conclusion” chapter of the volume, by Robert K. Perrons, draws together the various narrative strands running through the text and speculates on what lies ahead. While obvious differences exist between each



sector of the extractive industries, and indeed between different contexts and companies, there are shared challenges: increasingly tough conditions under which to maintain efficiency and productivity, coupled with burgeoning environmental and social demands. Perhaps most encouragingly—and something which this book hopes to demonstrate, through appropriate use of technology and innovation—the means are seemingly there to deal with these circumstances and to follow directions that were inconceivable in living memory. We hope that this book provides a conceptual and pragmatic taste of the current groundswell in new approaches to manage and advance the extractive industries, and acts as an inspiration for continued progress in future research and implementation of these ideals.