ENVIRONMENTAL IMPACTS FROM THE DEVELOPMENT OF UNCONVENTIONAL OIL AND GAS RESERVES

The development of unconventional oil and gas shales using hydraulic fracturing and directional drilling is currently a focal point of energy and climate change discussions. While this technology has provided access to substantial reserves of oil and gas, the need for large quantities of water, emissions, and infrastructure raises concerns over the environmental impacts. Written by an international consortium of experts, this book provides a comprehensive overview of the extraction from unconventional reservoirs, providing clear explanations of the technology and processes involved. Each chapter is devoted to different aspects including global reserves, the status of their development and regulatory framework, water management and contamination, air quality, earthquakes, radioactivity, isotope geochemistry, microbiology, and climate change. Case studies present baseline studies, water monitoring efforts, and habitat destruction. This book is accessible to a wide audience, from academics to industry professionals and policymakers interested in environmental pollution and petroleum exploration.

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Preface

The combination of directional (e.g., horizontal) drilling and hydraulic fracturing ("fracking") has revolutionized oil and gas exploration, especially in the last two decades. They have been applied to conventional reserves, allowing for greater recovery, and for the development of "tight" deposits, primarily shales, releasing previously untapped reserves. The Energy Information Administration (EIA) has estimated that globally, shale gas reserves may contain 7,577 Tcf (trillion cubic feet) and shale oil reserves may contain 419 billion bbl (barrels). Unconventional shale extraction has reached commercial-level production in the United States and Canada, while increasing development is happening in China and Argentina. Australia has been developing its coal bed methane deposits, especially in Queensland, and there has been exploratory drilling in England (Bowland Basin), Germany (Niedersachsen), and Poland. At the same time Scotland, France, and parts of Australia have a moratorium or outright ban on the process. While many celebrate the potential economic benefits, concerns about environmental impacts that include water contamination, air quality degradation, habitat fragmentation, and the continued contribution to climate change have been raised. The "slick water" stimulation and "fracking" rely on a complicated mix of chemicals and "proppant" (fine grained silica sand), while the shales themselves contain salt brines (e.g., sodium, chloride, bromide), distinct trace element content (e.g., barium, strontium), and heavy metals including naturally occurring radioactive materials (NORMs). The extraction and distribution operations depend on complex infrastructure such as compressor stations, cryogenic processing plants, and an extensive network of pipelines for water and gas (e.g., gathering lines, transmission lines). Solid and liquid waste disposal has also presented challenges, with some solutions resulting in unexpected adverse consequences such as the generation of trihalomethanes in municipal water and radium (^{226}Ra) contamination as a result of road brining. Climate change has also put the focus on the global impacts of continued extraction and use of fossil fuels, with many nations signing the Paris Climate Agreement of 2016, promising significant carbon dioxide emissions reductions.

Despite the global expansion of unconventional oil and gas exploration, the literature has been scrambling to keep pace. There are numerous popular books providing some of the history behind it, personal stories, and even fiction. There are also a number of industry-published books that delve into the technical aspects such as proppant and fluid

characterization. We realized there was a need and interest in a volume that addressed the environmental impacts. The impetus for this book initially came out of a two-day conference held at Duquesne University in November 2013 ("Facing the Challenges: research on shale gas extraction symposium"). There were twenty-two scholarly presentations covering a broad range of topics, the majority of which dealt with the environmental impacts. While a few of these presentations were published as a special issue of the journal *Environmental Science and Health, Part A* (2015, volume 50, issue 5), the symposium provided a framework for a comprehensive compendium and a potential list of contributors. We also reached out to other colleagues working in the field, especially several outside the United States to include contributions from Europe, Canada, and Australia. The Marcellus and Utica Shales of the Appalachian Basin have been, in many respects, the testing grounds for unconventional shale development in other parts of the country and the world. The authors we have solicited chapters from are known for their pioneering work. In the end we compiled 16 contributions. The book is divided into three sections: Overview, Environmental Analysis, and Case Studies. The Overview comprises four chapters. Chapter 1 provides an overview of the global unconventional oil and gas reserves and the status of their development at the time of this publication. Chapter 2 is an introduction to the development of unconventional oil and gas reserves based primarily on experience with the Appalachian Basin. Chapter 3 covers developments in Australia, where both gas shales and coal bed methane deposits are being tapped. Chapter 4 looks at the trends and challenges in governance, addressing issues related to mineral rights ownership, royalties, and regulations. The Environmental Analysis section, the bulk of the book, comprises nine chapters. Chapter 5 covers air quality issues. Chapter 6 tackles fugitive methane and its impact on climate change and lifecycle assessment. Chapter 7 provides a comprehensive look at water usage and management. Induced seismicity, as a result of hydraulic stimulation and waste injection facilities, is addressed in Chapter 8. Both drill cuttings and produced water from shales are known to contain naturally occurring radioactive materials (NORMs), a subject covered in Chapter 9. The next two chapters focus on the use of isotopes as tracers to identify sources, namely metal isotopes (Chapter 10) and methane isotopes (Chapter 11). The last chapter in this section discusses the microbiology (Chapter 12). The last section, Case Studies, provides assessments from a more holistic approach. The first chapter in this section evaluates water chemistry using mass ratio analyses to identify potential sources of contamination (Chapter 13). The second is a baseline study of a paired stream system in southwestern Pennsylvania, which was completed early on in the development of the Marcellus shale (Chapter 14). The next chapter (Chapter 15) addresses the effects of shale gas development on forest landscapes and ecosystems. The final chapter reports on the activities of the Three Rivers Quest Project, a consortium of several regional universities that have been monitoring the water quality of the three rivers of the Ohio River Basin (Allegheny, Monongahela, Ohio) for the last decade (Chapter 16).

In putting together this volume our goal was to present a broad picture of the development of unconventional oil and gas shales. Without this background it will be difficult to address the challenges, especially considering the legacy of environmental impacts from

conventional oil and gas extraction. It is our hope that this book will be accessible to a wide audience of readers, from industry to academics, as well as laypersons interested in the subject matter. The authors would like to thank all the contributors, as well as the Colcom Foundation and Heinz Endowments for support over the years. A special thanks to Robert Donnan for his amazing photographs, and to Dr. David Kahler whose assistance with the formatting of the equation-heavy chapters was greatly appreciated.