The Handbook of Environmental Remediation

Classic and Modern Techniques

Edited by Chaudhery Mustansar Hussain

ROYAL SOCIETY OF CHEMISTRY

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Preface

Environmental remediation is a process that aims to remove or reduce the levels of contaminants in soils, groundwater, surface water, air or other environmental media in order to improve ecological effects and public health and/or facilitate the redevelopment of contaminated sites. A number of remediation technologies have been developed, some of which are routinely used and others that require further testing for their effectiveness in the field. Although remediation is necessary to improve environmental conditions, there may be risks associated with environmental remediation, including the generation of secondary waste streams, the risk of future leaching of contaminants that were immobilized but not degraded or the emission of harmful particulate matter. The United States and Europe have implemented various regulatory and statutory approaches to facilitate the environmental remediation of contaminated sites. The objective of this handbook is to summarize the recent advances in a variety of technologies for environmental site remediation. Every effort has been made to include all state-of-the-art site remediation techniques and specific examples of the application of each method are provided where possible, and references for each technology are cited if more detailed information is desired. The most recent and emerging remediation technologies are given special consideration. Moreover, special attention is paid to those approaches that tend to be green and sustainable for modern developments. Finally, economic aspects and health and safety issues are also considered in detail.

To place all of the collective knowledge into perspective and bring realism to the overall thoughts presented, the book is divided into 18 chapters. In Chapter 1, a comprehensive overview of new thoughts and new avenues in the field of environmental protection and environmental engineering is given. Chapter 2 discusses various kinds of hazardous wastes, their sources and their end-of-pipe disposal. An overview of *in situ*, *on situ* or *ex situ*

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thermal desorption methods for cleaning contaminated soils is provided in Chapter 3. Chapter 4 deals with soil vapor extraction (SVE), which is used extensively as an *in situ* remediation method for removing volatile organic compounds from subsurface soil. Chapter 5 describes the approaches proposed for the treatment of contaminated soils, focusing in particular on those based on electrokinetic phenomena. Chapter 6 provides an understanding of pollutant immobilization mechanisms, systematic formulation design and the rigorous evaluation of stabilization/solidification. An overview of permeable reactive barriers (PRBs), focusing on emerging aspects and the future of the technology, is presented in Chapter 7. Chapter 8 gives an overview of soil contamination and summarizes recent progress in thermal decontamination processes. Chapter 9 focuses on composting as a bioremediation method to treat contaminants present in the environment. Chapter 10 focuses on the phytoremediation technique, which has been expanding rapidly in recent years as a method to solve environmental contamination problems owing to its environmental and economic benefits. In Chapter 11, biostimulation and bioaugmentation as eco-friendly *in situ* bioremediation approaches are explored. Chapter 12 explains strategies for enhancing soil phytoremediation and biomass valorization for contaminated land all over the world. In Chapter 13, recent progress in landfarming to clean up or remove contaminants from soil is described. Chapter 14 describes the most recent applications and studies of ultrasound-assisted remediation methods. Chapter 15 summarizes the historical development of electrochemical processes for wastewater treatment and discusses their fundamentals. Chapter 16 reports on the types and various applications of nanoparticles in environmental remediation. A very important criterion is the efficiency of the method adopted for the remediation of contaminated areas considering both human health and general environmental well-being, as depicted in Chapter 17. Finally, the future of environmental remediation methods in terms of the challenges facing remediation in the context of modern society is debated in Chapter 18.

The diversity of the authors of the various chapters and their experience in many disciplines reveal the interdisciplinary nature of this handbook, as a result of which the reader has available a wealth of knowledge in a single place.

Overall, the aim of this handbook is to provide a reference work for scientists, engineers, researchers, consultants and regulators who are searching for new and advanced techniques for the remediation of varied environmental sites. Moreover, university students will find this book useful in their research and understanding of advances in environmental site remediation techniques and beyond.

The editor and contributors are well-known researchers, scientists and true professionals from academia and industry. On behalf of the Royal Society of Chemistry, we express our appreciation to all the authors for their magnificent and outstanding efforts in the preparation of this handbook. Special thanks are due to Dr Michelle Carey (Senior Commissioning Editor) and Connor Sheppard (Editorial Assistant) at the Royal Society of Chemistry for their enthusiastic support and committed help during this project. Finally, the Royal Society of Chemistry is especially thanked for publishing this handbook.

Chaudhery Mustansar Hussain

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CHAPTER 1

Innovation in Environmental Remediation Methods

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1.1 Introduction

Environmental engineering science and chemical process engineering are today witnessing immense scientific challenges and extensive scientific intricacies. Technological vision, great scientific motivation and the futuristic vision of environmental engineering science are the forerunners towards a new visionary scientific order in the field of science and engineering. Global water shortages and climate change during this century are devastating the global scientific landscape. In this chapter, the authors consider in depth the immediate necessities of human civilization such as energy and environmental sustainability. Water, energy, food, shelter and education today stand as major pivots in the success of global human scientific endeavor. The world of environmental engineering, drinking water treatment and industrial wastewater treatment is in the process of new scientific rejuvenation. Futuristic vision and future research trends should be targeted towards greater scientific emancipation in the fields of nanotechnology,

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nanomaterials and engineered nanomaterials. The targets of human civilization and human scientific research pursuits should be towards the application of nanomaterials in diverse areas of science and engineering. Technology and engineering science currently have few answers to the arsenic and heavy metal contamination in drinking water prevalent in many developing and developed countries around the world.

This chapter considers in depth the scientific needs, the scientific vision and the deep scientific insight in membrane science applications in environmental protection. The authors expound the importance of advanced oxidation processes as a strong non-conventional environmental engineering tool. The current need is mitigation of global water shortages and global climate change. Hence human civilization needs to be reorganized and restructured as regards environmental protection and the manifold needs of environmental remediation. Technological and scientific validation are also equal necessities of the scientific realization of environmental engineering. The authors' deep insight is brought to bear on the imminent needs of chemical process engineering and also novel separation processes. Membrane science needs to be restructured and reorganized based on the passage of scientific history and the future visionary time frame. This chapter should be an eye-opener towards the scientific intricacies of innovations in environmental engineering techniques.

1.2 The Vision of This Chapter

Human civilization and human scientific research pursuits are today at the center of deep scientific vision and engineering introspection. Today, environmental engineering science is an engineering success. In a similar vein, chemical process engineering, material science, nanotechnology and petroleum engineering are currently at the forefront of human scientific endeavor. The vision of this chapter is to open new doors of scientific innovation in the field of conventional and non-conventional environmental engineering tools. The success and the validation of the science of environmental remediation are multifarious and versatile. This chapter targets the widely observed necessities of the technology, engineering and science of environmental remediation. Human scientific endeavor will then usher in a new era in the field of energy and environmental sustainability. Sustainable development is the one of the greatest needs of human civilization today. The areas of energy and environmental sustainability are of immense concern in modern-day human civilization. This chapter reiterates the great scientific needs of sustainability applications in human society.

1.3 The Needs and the Rationale of This Chapter

The status of the environment today is extremely dismal. The needs and the rationale of this chapter go beyond deep scientific imagination. Environmental remediation is the greatest current need. The authors emphasize particularly environmental sustainability and conventional and non-conventional environmental engineering techniques. The world of science today stands transfixed with the ever-growing concerns regarding environmental disasters, loss of ecological biodiversity and global climate change. In such a situation, this chapter is intended to reveal the scientific intricacies and scientific insight in the field of environmental engineering science. The great scientific determination and perseverance of humans, mankind's scientific stature and the futuristic vision of environmental engineering will all lead a visionary approach in the true realization of both energy and environmental sustainability. Humankind is currently faced with an immense scientific conundrum. The world today stands mesmerized with the growing concerns of global climate change, a total lack of clean drinking water in some parts of the world and the challenges of sustainable development. Environmental sustainability is therefore the greatest need at present. The definition of "sustainability" by Dr Gro Harlem Brundtland will be re-envisioned and restructured in the present context of environmental engineering and environmental protection. Science, technology and engineering therefore all need to be revamped and reorganized with the passage of scientific history and time. In this chapter, the authors re-emphasize the need for environmental sustainability in human scientific progress. Millions of people around the world are without pure drinking water and with improper sanitation. This is the need and the rationale of this study. Mankind's extensive scientific profundity, the futuristic endeavors of science and the needs of sustainability science will all be torchbearers towards a new visionary era in environmental remediation.

1.4 Environmental Sustainability and the Vision for the Future

Environmental sustainability, water purification and integrated water resource management are today linked with each other as a result of extensive scientific vision and scientific perseverance. The vision of environmental engineering techniques is manifold and versatile. Scientific truth, deep scientific perseverance and scientific candor are hallmarks towards a new visionary era in the field of environmental remediation. Today, the crisis of global warming and frequent environmental disasters are stimulants to future research and development directions. Arsenic and heavy metal groundwater pollution is today devastating the fabric of many developing and developed nations around the world. The world of environmental engineering and chemical process engineering is truly struggling with this ever-growing and intricate issue, hence the vital need for global environmental remediation and environmental sustainability. Many countries around the globe do not have proper drinking water provision and lack proper sanitation. The authors stress these vital issues and open up a new world order in environmental engineering and environmental sustainability.

Barrow[1] discussed in detail environmental management and development. Environmental management and sustainable development are two opposite sides of the visionary coin today. The author discussed in great detail the theory of and approaches to environmental management in developing countries, resource management issues by sector, water, coastal and island resources, agriculture, land degradation, food security, biodiversity resources, atmospheric issues and environmental tools and policies. Environmental management and development are both difficult domains to define.[1] The former can be a goal or vision, an approach to steer a process, the application of a set of tools and a more philosophical exercise. Development can be a goal or vision, also the application of some visionary tools and an attempt to steer a process. The science of environmental protection in a similar vein is in the process of new scientific rejuvenation.[1] Providing a universally accepted definition of sustainable development is absolutely impossible. It is a veritable process of change that can enhance, accelerate, slow, stagnate or push backwards. Development can be increasingly seen as a social transformation through the use of capital, technology and knowledge.[1] Clearly, it is immensely difficult to separate the concepts of development from cultural, ethical and religious outlooks. Sustainable development is a major need of human scientific progress today.[1] Development management has evolved independently of the vast domain of environmental management but the concepts often overlap. Barrow's book opened up new scientific thoughts and new scientific innovations in the field of environmental sustainability for decades to come.[1]

Barrow[2] subsequently discussed environmental management for sustainable development, considering the theory, principles and concepts of environmental management, environmental management approaches, standards, monitoring, modeling, auditing and coordination. His book provided a deep insight into pollution and waste management. As already stated, today environmental management and sustainability are two opposite sides of the visionary coin.[2] Sustainability is an important need for present-day human civilization. The author discussed the goal of sustainable development, multidisciplinary and interdisciplinary approaches, concerns for limits, hazards and potential, short-term planning, translation from theory to practice and the awareness of the need to change the ethics of people, businesses and governments.[2] He redefined the concept of environmental management fundamentals and its goals. He also specifically focused on environmental management and science, biodiversity, biosphere cyclic processes and the great environmental crisis that the world is facing.[2]

LeBlanc[3] presented a detailed review that depicted in depth the implications for industry and the infrastructure involved in demystifying the risk of climate change. The premise of the book was that long before the Paris Agreement, scientists, engineers, businessmen and -women, public officials, academics and non-governmental organizations throughout the USA and the world were at the threshold of the issue of solving the myriad problems associated with anthropogenic climate change and global warming,[3] hence it is time to share research ideas amongst diverse people in diverse areas of scientific endeavor. This volume covers implications for industry and infrastructure in (1) a stand-alone chapter on the Montreal Protocol, (2) a chapter on industry and infrastructure concerns, (3) a section devoted to sustainability and strategic planning and (4) a chapter on climate science and business risks.[3] The scientific challenges in mitigating global climate change are deliberated and discussed in detail.

Katman[4] discussed and deliberated on global climate change, the environment and energy in great detail. Climate change represents a fundamental challenge for global environmental and energy sustainability. Global warming and climate change are both environmental and sustainable development issues.[4] His book aimed to cover both sides of the coin in providing comprehensive information concerning climate change, environment and energy domains. The chapters in this book represent multidisciplinary perspectives with considerable elaboration on their interdependence. Global climate change is related to an increase in the temperature of the atmosphere and the oceans.[4] Some gases, such as carbon dioxide, methane, nitrous oxide and hydrofluorocarbons, increase the temperature of the atmosphere. The immense skill and depth of human scientific endeavors and the great scientific success of environmental engineering innovations are minutely deliberated in this book.[4]

The pursuit of human scientific research and technological and engineering innovations are at the crossroads of vision and deep profundity. Throughout this chapter, the author rehearses the scientific needs of environmental and energy sustainability in the furtherance of science and engineering.

1.5 The Present State of the Environment and the Success of Scientific Endeavor

The present state of the human environment is very dismal and thought provoking. The provision of basic human needs such as energy and water is a scientific imperative of modern science today. In a similar vision, global warming and the depletion of fossil fuel resources are current concerns of human civilization. Scientific research pursuits and the participation of civil society are major cornerstones of human progress. Global warming and global climate change, frequent environmental disasters, depletion of fossil fuel resources and loss of ecological biodiversity are major scientific problems for human civilization. At such a crucial juncture of scientific history and time, important needs are scientific innovation and greater scientific emancipation in research and development initiatives. In this chapter, the author reiterates the success of science and engineering, the intricacies and struggles of technology and engineering science and the futuristic vision of water science and technology. The main need is environmental sustainability. This chapter goes beyond scientific imagination and opens up new doors of scientific innovation and instinct in the fields of both chemical process engineering and environmental engineering science. The present state of the environment can be mitigated if new insights and new techniques and scientific innovations are envisioned. Contributions from scientists, engineers and the general population are important needs of human civilization today. Scientific research pursuits should be targeted towards both conventional and non-conventional areas of environmental engineering techniques.

1.6 Scientific Sagacity and the Vast World of Environmental Remediation

Scientific knowledge and ingenuity are powering their way forwards towards greater emancipation of environmental remediation and environmental sustainability. The areas of chemical process engineering, nanotechnology and petroleum engineering are today changing the face of human civilization. Depletion of fossil fuel resources and global warming need to be mitigated at the earliest opportunity. The vast world of environmental remediation and environmental protection needs to be re-envisioned and re-envisaged as science and engineering move forwards towards a new visionary era. Scientific insight, in a similar manner, needs to be re-emboldened with the passage of scientific history and time. Chemical process engineering and novel separation processes also need to be widened if environmental disasters are to be mitigated. The contribution of scientific vision should come from scientists, engineers and the civil society. Research and development initiatives in membrane science and desalination are major needs. In a similar vein, industrial wastewater treatment and waste management are important needs of human civilization today. The groundwater contamination crisis is really baffling the global scientific scenario. Global water shortages need to be mitigated. In this chapter, the authors clearly elucidate the necessity for environmental protection and environmental remediation and also groundwater remediation in the furtherance of science and engineering globally. Drinking water treatment will be the target of scientific research projects and the greater emancipation of science and engineering. Water purification science also needs to be re-envisioned. Scientific insight and scientific vision will be truly emboldened if human civilization moves towards the most suitable paths of research and development initiatives in water science and technology. Globally, energy and environmental sustainability are targets of modern scientific rejuvenation. Global climate change and environmental and energy sustainability will surely open up new dimensions of knowledge in the field of environmental remediation in the decades to come.

1.7 Conventional and Non-conventional Environmental Engineering Techniques

Conventional and non-conventional environmental engineering tools are the greatest necessities of scientific research pursuits today. Advanced oxidation processes and membrane separation processes are at the center of deep scientific rejuvenation and great scientific regeneration. Novel separation processes such as in membrane science are currently at the focus of intense investigations. Water science and technology, wastewater management and integrated water resource management are major needs of human civilization. Primary, secondary and tertiary treatments of industrial wastewater needs to be re-envisioned and re-envisaged. In a similar vein, chemical process engineering, nanotechnology and membrane science need to be restructured. Advanced oxidation processes and membrane separation processes needs to be re-envisioned and reorganized as science and technology move towards new scientific and knowledge dimensions. In a similar vein, integrated water resource management, human factor engineering and wastewater management need to be overhauled.

1.8 Scientific Vision and Arsenic Groundwater Remediation

Scientific vision and major scientific endeavors in arsenic groundwater remediation are at the forefront of new rejuvenation. Modern science's great ingenuity, our extensive scientific knowledge and the advanced features of engineering science are the torchbearers towards a new visionary era in the field of environmental remediation. Groundwater and drinking water contamination by arsenic and heavy metals is today challenging the wide range of scientific expertise. This section considers in depth the scientific needs, the scientific successes and the scientific ingenuity in the application of environmental protection tools in mitigating the global water crisis and primary, secondary and tertiary treatments in environmental protection science.

Hashim *et al.*[5] considered in depth remediation technologies for heavy metal-contaminated groundwater. Great vision, skill and perseverance are major needs in scientific research in groundwater remediation today.[5] The contamination of groundwater by heavy metals originating from natural soil resources or from anthropogenic sources is a matter of great concern to human civilization. Remediation of contaminated groundwater is of the highest priority since billions of people around the world are dependent on groundwater for use as drinking water.[5] In this study, 35 approaches for groundwater treatment were reviewed in detail and classified into three large categories, namely chemical, biochemical/biological/biosorption and physicochemical treatment processes.[5] The authors discussed the natural chemistry, bioremediation and biosorption of contaminated water and organic/inorganic pollutants. ''Heavy metals'' is a general collective term that applies to the group of metals and metalloids with density greater than 4000 $kg\,m^{-3}$ or five times greater than that of water. The authors discussed in detail the sources, chemical properties and speciation of heavy metals in groundwater. Scientific vision and challenges will lead towards the true emancipation of environmental and energy sustainability in modern science today. The authors considered chemical treatment technologies, *in situ* treatment using reductants, reduction by dithionite, reduction using iron-based technologies, soil washing, *in situ* soil flushing, *in situ* chelate flushing and *in situ* chemical flushing.[5] Technology, engineering and science are today advancing at a rapid pace. In a similar vein, environmental protection and environmental remediation are in the process of a new scientific re-generation. This paper opens up new thoughts, new visionary domains and a new futuristic vision in the field of heavy metal groundwater remediation.

1.9 Advanced Oxidation Processes and the Road to Scientific Wisdom

Advanced oxidation processes and non-conventional environmental engineering tools are current requirements in science and engineering. Human civilization's scientific achievements, the success of research projects and the futuristic vision of both environmental engineering and chemical process engineering will all be contributors towards greater emancipation of the science of sustainability. The road to scientific wisdom in environmental remediation is wide and versatile. A great need of mankind is energy and environmental sustainability. The major scientific and technological challenges are changing and challenging the wide scientific ramifications of environmental remediation. The world of environmental engineering science today stands transfixed at the serious issue of global climate change and frequent environmental disasters. Global warming and frequent environmental catastrophes are today devastating the overall scientific landscape.

1.10 Membrane Science and Other Novel Separation Processes

Developments in membrane science and other novel separation processes are challenges in current scientific research pursuits. Membrane science and water purification are two opposite sides of the visionary coin. In a similar vein, reverse osmosis and the science of desalination are today integrated with each other. The futuristic vision of environmental engineering science, the world of technological validation and the provision of basic human needs such as water, energy and education are the forerunners towards a new visionary era in the field of science and technology. Today, many developed and developing countries around the world are at the threshold of the world's greatest environmental disaster – groundwater contamination by arsenic and heavy metals. At such a crucial juncture of scientific and technological history and time, water purification and industrial wastewater treatment need to be re-envisioned and re-envisaged with wide scientific horizons and great determination. Today, novel separation processes and advanced oxidation processes are at the forefront of science and engineering.

1.11 Recent Scientific Endeavors in the Field of Advanced Oxidation Processes

Advanced oxidation processes and hybrid advanced oxidation processes are today undergoing new scientific regeneration. Water purification, drinking water treatment and industrial wastewater treatment are witnessing major scientific challenges and intricate scientific barriers. This section reiterates the wide needs of science and technology today in confronting and mitigating environmental protection issues. Environmental protection and environmental remediation are currently changing the face of human scientific endeavor. Hybrid advanced oxidation processes are necessities for tomorrow's visionary world of environmental engineering science.

Al-Kdasi *et al.*[6] reviewed the treatment of wastewater by advanced oxidation processes. The use of conventional textile wastewater treatment processes is a very challenging area for environmental engineers and environmental scientists with increasing environmental regulations globally.[6] Technological vision, great scientific depth and the futuristic vision of environmental engineering will all be forerunners towards a new era in the domain of advanced oxidation processes. Conventional treatments will not be feasible as 53% of 87 colors have been identified as non-biodegradable.[6] Technological approaches and vision therefore need to be reorganized. Advanced oxidation processes hold great promise for providing alternative technology for better treatment and protection of the environment. Textile wastewater includes a large variety of chemicals that pose an environmental challenge in the textile industry not only as a liquid waste but also in its chemical composition.[6] The authors considered in detail textile wastewater characteristics, the wide range of advanced oxidation processes, ultraviolet, ozone and ozone–ultraviolet treatment and ozone–hydrogen peroxide and other hybrid advanced oxidation processes.[6] Advanced oxidation processes (AOPs) represent a promising and powerful treatment for refractory and toxic pollutants in industrial wastewater. There are many research areas that need to be re-envisioned, such as (1) study of the efficiency of different candidate processes under different controlled conditions, (2) identification of intermediates and by-products and their toxicity, (3) study of the sequence operation effect of AOP reagents and (4) identification of scale-up parameters and criteria for cost-effectiveness.[6] The authors discussed in depth the various integrated AOPs with the sole aim of the furtherance of science and engineering.[6] The main pillar of this study was detailed consideration of AOPs and integrated AOPs.[6] Conventional oxidation processes have extreme difficulty in oxidizing dyestuffs and complex structures of organic compounds at low concentration or if they are especially refractory and recalcitrant to certain compounds. To ease this problem, AOPs have been developed to generate hydroxyl radicals by different techniques. AOPs involving a combination of ozone, hydrogen peroxide and ultraviolet radiation showed the greatest promise for degrading textile industry wastewater. The authors presented a case study of an industrial wastewater treatment and wastewater management scenario.[6] Composite textile industry wastewater is characterized by measurements of biochemical oxygen demand, chemical oxygen demand, suspended solids and dissolved solids.[6] The goal of any AOP design is to generate and use hydroxyl free radicals as a strong oxidant to destroy compounds that cannot be oxidized by conventional oxidants, demonstrating the great importance of AOPs. The authors reviewed in depth the various AOPs and hybrid processes and gave a clear picture of conventional and non-conventional oxidation processes. Human civilization's impressive scientific endeavors and the futuristic vision of technology and engineering science will surely open a new chapter in the field of environmental engineering science.[6]

Gogate and Pandit[7] discussed in great detail important technologies for wastewater treatment and oxidation technologies under ambient conditions. In recent times, owing to the increasing presence of inorganic and organic molecules that are refractory to the microorganisms in wastewater streams, conventional biological methods have been found to be redundant,[7] hence the introduction of new technologies to degrade these refractory molecules into smaller molecules that can be further oxidized by biological methods has become extremely important.[7] This study highlighted five different oxidation processes operating under ambient conditions, namely catalytic oxidation, photocatalytic oxidation, Fenton's chemistry, ozonation and the use of hydrogen peroxide.[7] The authors discussed the optimum operating conditions and reactor design aspects with a comprehensive overview of the various applications to wastewater treatment and integrated wastewater management in recent years.[7] AOPs are defined as processes that generate hydroxyl radicals in large quantities that can oxidize the majority of the complex chemicals present in industrial wastewater,[7] including cavitation, photocatalytic oxidation and Fenton's chemistry. Technological and scientific challenges and vision in the field of oxidation chemistry and environmental engineering science were discussed in depth.[7] The other areas of research endeavors covered included optimum parameters for sonochemical reactors and a detailed discussion of work carried out in recent years and the wide scope of this research work. The vision of science, the major scientific motivation and the needs of scientific and technological validation will all be the torchbearers towards a new era in the field of conventional and non-conventional environmental engineering tools. This paper highlights these important areas.[7]

Wang and Xu[8] discussed in detail AOPs for wastewater treatment and the formation of hydroxyl radicals and their application. AOPs, defined as those technologies that utilize hydroxyl radicals for oxidation purposes, have attracted considerable attention in research and development initiatives in recent years. These processes have been successfully applied for the removal and degradation of toxic pollutants in industrial wastewater.[8] Controversial aspects of the mechanism of the degradation of pollutants were discussed in detail. The authors reviewed the application of these processes for the removal of different kinds of toxic pollutants from wastewater, including aromatic compounds, dyes, pharmaceutical compounds and pesticides, with emphasis on the parameters assessed, effectiveness of removal and the intricate degradation mechanism of pollutants.[8] The science of AOPs has been advancing at a rapid pace in recent years.[8] This paper presented new thoughts and a new vision in the area of non-conventional environmental engineering techniques.[8] Six types of AOPs, namely radiation, photolysis and photocatalysis, sonolysis, electrochemical oxidation, Fenton-based reactions and ozone-based processes, were discussed in detail.[8]

Munter[9] discussed in detail the current status and prospects of AOPs. The paper provided a deep insight into the theoretical basis, efficiency, economics, laboratory and pilot plant testing, design and modeling of different AOPs. Hazardous organic wastes from industrial, military and commercial operations represent one of the greatest challenges to environmental engineers. Scientific vision, advances in science and engineering and the needs of engineering science will all be torchbearers towards a new visionary era in the field of environmental engineering science.[9] AOPs are viable alternatives to the incineration of wastes, which has serious disadvantages.[9] Conventional incineration needs to be phased out as science and engineering advance. Incineration releases toxic compounds such as polychlorinated dibenzodioxins and -furans into the environment *via* incinerator off-gas emissions and fly ash. Technological advances are currently at a high level in the global scientific scenario,[9] and in a similar vein AOPs are among the avenues of new scientific regeneration. The definition of an AOP is "near ambient temperature and pressure water treatment processes which involve the generation of hydroxyl radicals in sufficient quantity to affect water purification".[9] Water purification and industrial wastewater management represent a major scientific vision in the field of environmental engineering science. The authors discussed in detail the use of non-photochemical methods, ozonation at elevated pH, ozone and hydrogen peroxide, ozone and a catalyst, a Fenton-based system and photochemical methods.[9] The photochemical methods included the use of ozone and ultraviolet radiation, hydrogen peroxide and ultraviolet radiation, ozone and hydrogen peroxide and the wide domain of phocatalytic oxidation. The study also compared various AOPs and modeling of environmental engineering tools.[9]

The science and engineering of environmental remediation are today motivating new scientific ingenuity. The vision and challenge of environmental engineering and chemical process engineering are surpassing scientific barriers. Throughout this chapter, the authors specifically focus on the needs of science in the furtherance of human society. Water is a primary component in the vision of science today, and the authors reiterate this important aspect of science and engineering.

1.12 Recent Research Pursuits in Membrane Science

Membrane science and novel separation processes are a major vision and challenge of science today. Current research endeavors in membrane science are witnessing major scientific challenges. Membrane science and non-conventional environmental engineering tools are at the forefront of scientific innovation. Water science and technology are changing the face of human scientific endeavor. This chapter reveals the scientific insight and success in the field of environmental engineering.

Matsuura *et al.*[10] described recent advances in membrane science and technology in seawater desalination with technological advances in the Middle East and Singapore. Research and development initiatives regarding seawater desalination membranes are moving forward at a rapid pace and remarkable achievements in the performance of the membranes have been demonstrated.[10] These tremendous scientific advances in membrane science and desalination science continue today. The first historical and remarkable discovery of the Loeb–Sourirajan asymmetric reverse osmosis membrane allowed seawater desalination on a large scale. The fluxes of currently available commercial membranes are an order of magnitude higher than those of the reverse osmosis membranes of the 1960s with salt rejection as high as 99.8%. Further improvements in the development of membranes resulted in furtherance of the scientific vision in membrane separation processes.[10] Moreover, the fabrication of membranes that can reject boron, arsenic and organic compounds of low molecular weight to greater extents are the vision of numerous research and development initiatives.[10] Membranes that can withstand ultra-high pressures for seawater desalination and membranes that are operable at ultra-low pressures for seawater and brackish water desalination have been achieved for drinking water production.[10] It is reported that globally 96.5% of the Earth's water is located in the seas and oceans and 1.7% in the ice caps, and only 0.8% is considered to be fresh water with the rest being brackish water.

Technological and scientific validation and great scientific ingenuity are required by human civilization today.[10] The global shortage of water and the unending issue of global climate change are currently major problems the for scientific community. Over 1 billion people are without clean drinking water and approximately 2.3 billion people are living in water-stressed regions around the world.[10] Current technology and engineering have few answers to the ever-growing concern about arsenic groundwater contamination. In a groundbreaking approach, scientists and engineers around the world started research projects in the wide domain of water reuse, reclamation and desalination, and this well-researched study[10] opened up a new vision and with new scientific facts in the field of membrane science and desalination science. Scientific knowledge in water science is now reaching new heights.[10] Current desalination technology consists of two methods: a thermal desalination method that has been developed over the past 60 years and the membrane processes that have been developed over the past 40 years. Reverse osmosis, nanofiltration and electrodialysis are typical membrane processes available for desalination.[10] Reverse osmosis and nanofiltration are called pressure-driven membrane processes since the transmembrane pressure difference is the driving force for the mass transport, whereas for electrodialysis the electrical pressure difference is the driving force for the mass (ion) transport. The authors specifically focused on the scientific origins and success and the applications of seawater desalination, water purification and membrane separation processes. The science and engineering of environmental protection are today assuming great importance as the global water shortage affects the global engineering scenario. Nanotechnology and nanofiltration are currently important avenues of global scientific research projects in developing and developed nations around the world.[10] This study[10] is a veritable eye-opener regarding the basic needs of humans, including energy and environmental sustainability.

Wenten[11] discussed in detail recent developments in membrane science and its industrial applications.[11] Synthetic membrane history began in 1748 when the Frenchman Jean-Antoine Nollet (Abbé Nollet) demonstrated semipermeability for the first time, showing that an animal bladder was more semipermeable to water than to wine. A century after this remarkable discovery, Fick published his law of diffusion, which scientists around the world still use as a first-order description of membranes.[11] Fick was the first to prepare and study artificial semipermeable membranes. This study[11] highlighted the scientific basis of membrane science. Wenten discussed membrane processes with respect to the membrane industry and market potential and described emerging membranes such as high-performance reverse osmosis membranes, supported liquid membranes, inorganic membranes, composite hollow-fiber membranes, membrane contactors and membrane reactors. This entire study represents a visionary approach towards scientific emancipation in water science and environmental remediation science.[11]

Cheryan[12] discussed and elucidated in detail ultrafiltration and microfiltration. The development of the Loeb–Sourirajan membrane in 1960 revolutionized scientific resources and vision. The application of membranes suffered major barriers in its formative years but today they are a boon to science and replete with scientific achievements. Filtration is defined as the separation of two or more components from a fluid stream, such as the separation of solid immiscible particles from liquid and gaseous streams. The primary role of a membrane is to act as a selective barrier, and the membrane acts as a barrier to the movement of solid particles. Membranes can be classified according to (1) the nature of the membrane, (2) the structure of the membrane, (3) the application of the membrane and (4) the mechanism of the membrane. Cheryan discussed in detail membrane chemistry, membrane structure and function, membrane properties, performance and engineering models and the wide area of fouling and cleaning, together with process design and applications and the vision and challenges of the science and engineering of ultrafiltration and nanofiltration.[12]

The science and engineering of environmental remediation are today being studied with great scientific and academic rigor. Water science and membrane science need to be integrated since water scarcity is an ever-growing concern and an impending disaster. The present authors strongly support the success of today's innovations in environmental remediation.

1.13 Nanotechnology in Groundwater Remediation and the Great Vision

Nanoengineering and nanotechnology in groundwater remediation are today major areas of scientific research. Nanotechnology is a multidisciplinary area of science and engineering that has gained in importance in the last few years. Nanoparticles represent a key area and promise many benefits through nano-enabled applications in multiple sectors and wide arenas.

Rajan[13] discussed the use of nanomaterials such as zerovalent iron and carbon nanotubes in environmental cleanup applications such as groundwater remediation, water reuse and desalination. There are currently major concerns regarding the issues associated with the use of nanomaterials with respect to the environment and human health. The vision of science, technological validation and the futuristic vision of environmental protection will surely be major players towards a greater understanding of nanomaterials and engineered nanomaterials.[13] An important scientific requirement is the need to elucidate the relationship between the properties of nanoparticles and their *in vivo* effects and to provide an effective strategy to tackle the harmful effects, and Rajan[13] considered in depth site remediation, nanoremediation, the application of nanoscale iron nanoparticles and the numerous applications of carbon nanotubes. Carbon nanotubes represent the next generation of nanomaterials and have diverse scientific and engineering applications.[13] The author's aim was to target the overall perspective of the use of nanoparticles to mitigate global water shortage issues by conventional means. Nanoremediation has great potential in the cleanup of large contaminated sites *in situ*, greatly reducing the cleanup time and reducing contaminant concentrations to zero. The author discussed in detail real-life scenarios to avoid the harmful effects of applications of nanomaterials.[13]

Kisku *et al.*[14] reviewed *in situ* remediation techniques for groundwater contamination. Versatile scientific advances and the technological and engineering achievements of environmental protection will be forerunners towards greater advances in bioremediation and nanoremediation technologies. Millions of people around the world depend on groundwater, which is the primary source of urban and rural drinking water,[14] highlighting the importance of integrated water resource management and innovations in environmental remediation. Owing to urbanization and industrialization, modern lifestyles have polluted this source of drinking water.[14] The challenge and the vision to remediate this primary source of water lie in the hands of scientists, engineers and the civil society. Major scientific challenges, scientific insight and the needs of engineering science and technology will all play a part in tackling groundwater remediation.[14] The authors discussed in depth typical sources of potential groundwater contamination by land-use category. They considered *in situ* remediation techniques, nanotreatment techniques, *in situ* soil vapor extraction treatment techniques, *in situ* chemical treatment techniques, *in situ* thermal treatment techniques, permeable reactive barrier techniques and bioremediation techniques. Bioremediation is currently a new vision and is approaching new challenges in environmental engineering science. This paper[14] opens up important areas of scientific judgment, scientific veracity and scientific ingenuity in the domain of environmental engineering applications in groundwater remediation. Today, technology and engineering are at the forefront of new scientific regeneration approaches. All research and development initiatives should be directed towards greater scientific truth and the scientific realization of environmental engineering science.

Mansoori *et al.*[15] redefined environmental applications of nanotechnology. Nanotechnology is an emerging field that covers a wide range of technologies that are currently under intense development at the nanoscale,[15] and today it plays a primary role in the development of innovative techniques to produce new products, to replace existing production equipment and to restructure new materials and chemicals with improved performance, resulting in a lower consumption of energy and materials and reduced harm to the environment. Environmental applications of nanotechnology address the development of solutions to present-day environmental problems and preventive measures to tackle future problems.[15] This paper provides a comprehensive review of the ongoing research trends in nanotechnology for environmental remediation, and various environmental treatments and remediations are discussed in detail.[15] The categories of nanoparticles studied include those based on titanium dioxide, iron, bimetallics, catalytic particles, clays, carbon nanotubes, fullerenes, dendrimers and magnetic nanoparticles.[15] Among the many applications of nanotechnology that have environmental implications, remediation of contaminated groundwater using nanoparticles containing zerovalent ion is one of the most prominent examples of a rapidly emerging technology with wide potential benefits. One of the main applications of nanotechnology is in the water sector. As freshwater resources are depleting, the immediate need is to innovate and redefine environmental engineering applications.[15] This study opens up new thoughts and a new futuristic vision in the field of environmental engineering tools. The application of carbon nanotube membranes in desalination is a promising innovation in environmental engineering science and water technology. Air pollution is another wide area where nanotechnology has prominent and important applications.[15] Achievements in scientific endeavors, the needs of scientific and technological validation and the success of scientific ingenuity will all be forerunners towards a new visionary realization in the fields of both nanotechnology and environmental engineering science. Filtration tools similar to water purification methods have extensive nanotechnology applications. In a similar manner, nanofiltration and integrated water resource management are linked to desalination techniques.[15] Nanofilters could be effectively applied to automobile tailpipes and factory smoke pipes to separate contaminants and prevent them from entering the atmosphere. In this paper, the authors discussed and reviewed processes used for environmental treatment with nanotechnology applications.[15] Technology and the engineering science of environmental protection and also nanotechnology are revealing new knowledge and scientific dimensions. The authors delved deeply into the world of nanomaterials and their environmental applications. In recent years, the technology of ultrasonic degradation has been studied in detail and used extensively in the treatment of environmental pollutants.[15] The authors considered in depth the removal of pollutants using titanium dioxide particles, and other areas included iron-based nanoparticles, bimetallic nanoparticles, nanoclays and carbon nanotubes.[15] The applications of dendrimers and fullerenes in environmental engineering science represent further areas of scientific investigation. This review investigated in detail all of the environmental aspects of nanotechnology and nanomaterials applications and opens up new doors to scientific innovation and scientific endeavor in the field of nanoscience and nanotechnology for the years to come.[15]

Anderson[16] discussed the efficient remediation of contaminated sites suffering from environmental pollution. The Swedish Environmental Agency is deeply concerned with the slow progress, low level of innovation and high cost of scientific endeavor in environmental remediation. More efficient and effective remediation of 1300 high-risk sites is needed if the national environmental objective of the Swedish government is to be met.[16] The total cleanup of contaminated sites, while reducing risks to human health and the surrounding environment, is known to have severe environmental effects, including greenhouse gas emissions, disturbances to human society and the production of large amounts of wastes and industrial pollutants. Technology and engineering science are today at the crossroads of vision, scientific endeavor and strong scientific perseverance.[16] These environmental concerns resulted in the concept of sustainable remediation and the vast world of bioremediation. A considerable number of sustainability assessment methods and tools are now available to assess the sustainability of remediation research and development initiatives developed at Chalmers University of Technology, Sweden.[16] The prime objective of Anderson's review was to study remediation efficiency and effectiveness in the research literature and to map out possible indicators to be used in future studies. Sustainability, whether it is environmental or energy, is an important need in human civilization today. The author discussed in detail sustainable remediation, efficient remediation and the vision of sustainable development. The basis of this review started from the Swedish Environmental Agency's concern regarding inefficient publicly funded remediation and sustainability projects. Mankind's great scientific skill and determination, scientific and technological validation and the needs of engineering science will all be forerunners towards a new visionary era in the field of environmental management and sustainable development. This project will open up a new chapter in the field of scientific vision and sustainable remediation.[16]

A United States Environmental Protection Agency Report[17] considered *in situ* treatment technologies for contaminated soil and discussed in detail a wide variety of *in situ* methods for the treatment of contaminated soil in both the vadose zone and saturated and unsaturated source zones. The *in situ* technologies outlined in this report involve the application of chemical, biological or physical processes to the subsurface to degrade contaminants without removing the bulk soil.[17] Compared with excavation and *ex situ* treatment, the use of these innovations has several benefits, such as removing deep contaminants, and generally the cost is lower. *In situ* methods are a scientific leader in today's science and engineering of environmental protection. The features of each *in situ* technology described include a basic description of the technology and the innovation involved, its implementation, its applicability based on contaminants and site characteristics, limitations, costs and the areas of its application. The treatment of contaminated sites is a major issue in environmental engineering science globally. This report represents an eye-opener towards the futuristic vision of *in situ* treatment technology.[17]

Zhang[18] discussed in depth the application of nanoscale iron particles for environmental remediation. Nanoscale iron particles represent a whole generation of remediation technologies and environmental engineering innovations,[18] and this could provide a wider perspective for the most challenging environmental engineering cleanup applications. Nanoscale iron particles have a large surface area and high reactivity,[18] and they provide enormous flexibility in *in situ* applications. Scientific research initiatives need to be redefined and reorganized as regards nanomaterials and nanotechnology applications. The success of science and engineering today is exceeding many versatile scientific boundaries and research initiatives involving nanotechnology and nanoparticles are opening up new doors of innovation in environmental engineering science.[18]

The science and engineering of environmental protection and environmental science are today witnessing major scientific overhauls and restructuring. The success of environmental engineering innovations lies in the hands of scientists, engineers and the civil society. The present authors strongly support current research endeavors in the field of environmental remediation.

1.14 Scientific Vision and Recent Developments in the Field of Drinking Water Treatment

Drinking water treatment and the application of nanomaterials and nanotechnology are today two opposite sides of the visionary coin. The authors reiterate the ever-growing concern regarding global heavy metal contamination of drinking water. The global scenario in environmental engineering is extremely grave This section opens up new thoughts and a new vision in the field of chemical process engineering and also nanotechnology and nanoengineering. Recent developments in the field of drinking water treatment are changing the face of scientific endeavor in both chemical process engineering and nanotechnology.

Shannon *et al.*[19] discussed in detail the science and technology of water purification for the coming decades. The world today stands transfixed at the ever-growing concerns regarding the provision of pure drinking water. Water purification, drinking water treatment and industrial wastewater treatment are imminent needs of human civilization. Some 1.2 billion people around the world lack access to safe drinking water, 2.6 billion people have little or no sanitation and millions of people die annually, *e.g.* 3900 children per day, from diseases transmitted from polluted water or human excreta, hence the ever-growing concerns regarding environmental engineering and water science innovations.[19] Technology and engineering have practically no answers to arsenic and heavy metal contamination in many developing and developed nations around the world. This paper provides a comprehensive review of the technologies of water purification and present-day innovations. Modern science today is in the midst of great scientific advances and ingenuity, and water science and technology are in the process of new scientific regeneration.[19] Water also strongly affects energy and food production, industrial output and the quality of our environment.[19] In this paper, the authors focus on disinfection, decontamination, reuse and reclamation and desalination. The overarching vision for providing safe water is affordably and robustly to disinfect water to protect against traditional and emerging pathogens, without creating more problems due to the disinfection process itself,[19] and investigations in the field of water purification are achieving many goals. Water-borne pathogens have a deleterious effect on public health, especially in the developing and disadvantaged countries of sub-Saharan Africa and Southeast Asia. Water-borne infectious agents responsible for the serious diseases involved include a variety of helminths, protozoa, fungi, bacteria and viruses.[19] Therefore, the effective control of water-borne pathogens in drinking water calls for new disinfection strategies and new innovations. The situation in developing countries is similar. International agencies and non-governmental organizations have introduced the use of sunlight irradiation to kill pathogens.[19] To develop alternatives to chlorine and UV disinfection for the control of water-borne viruses requires significant and important advances in understanding how viruses are inactivated by benchmark methods and new technologies. The overarching goal for the future of decontamination is to detect and remove toxic substances from water affordably and efficiently in a robust scientific manner.[19] Widely distributed substances such as arsenic, heavy metals, halogenated aromatics, nitrosamines, nitrates, phosphates and so on are known to cause immense harm to humans and the environment. The problems of detecting and accurately measuring toxic compounds in water and of selectively removing only those compounds are linked to each other.

Scientific endeavors, effective scientific predictions and the futuristic vision of water treatment will all be major players towards a new era in the fields of water purification, environmental protection and environmental sustainability. The overarching goal for the future of desalination is to increase the supply of fresh water *via* desalination of seawater. Saltwater accounts for 97.5% of all of the water on Earth.[19] Through continual improvements, particularly in the last decade, desalination technologies can now be applied effectively to desalinate seawater and provide fresh water for humans. This paper opens up new thoughts, a new vision and new scientific ingenuity and achievements in the broad domain of water purification and desalination for the decades to come.[19]

1.15 Integrated Water Resource Management and the Visionary Future

The science and technology of environmental remediation are today approached with great scientific and academic rigor. In a similar vein, integrated water resource management is at the forefront of major scientific revival and ingenuity. Today, the world of science and engineering stands transfixed at the formidable issue of water scarcity. At such a crucial juncture of scientific history and scientific vision, the needs of environmental engineering science are immense and groundbreaking. Technological validation, scientific buildup and the wider vision of water resource management will all be the forerunners towards a new visionary era. The challenges of conventional and non-conventional environmental remediation tools are similarly exceeding engineering boundaries. Scientific imagination and perception will surely be restructured as water science advances. Then the provision of basic human needs such as water, energy, food, shelter, education and sustainability will witness the ushering in of a new era. Diverse branches of engineering and technology will surely open new windows of scientific innovation and advances in the years to come.

1.16 Future Recommendations and Future Research Trends

Water purification and the deep scientific understanding of environmental sustainability and environmental remediation are today in the midst of great scientific hiatus and vision.[20,21,22,23] The future of environmental engineering science and chemical process engineering is vast and versatile. Future research trends and the future flow of scientific thoughts should be targeted towards greater scientific emancipation in the field of nanotechnology applications in environmental remediation. Nanomaterials and engineered nanomaterials are today widely involved in human scientific progress but are replete with major scientific barriers. The vision of environmental sustainability needs to be reorganized. In a similar vein, arsenic and heavy metal contamination of groundwater needs to be mitigated with a strong scientific basis. Nanotechnology has applications in almost every diverse area of science and engineering. Nanofiltration and membrane science are needed in global research and development initiatives in water treatment.[20–23] Desalination, on the other hand, will transform the scientific scenario of water purification. Technological challenges, scientific vision and great scientific motivation are immediate needs of research pursuits today. The authors stress the following points:

- Greater scientific understanding is needed in the field of applications of nanomaterials in environmental remediation.
- Desalination research should be at the forefront of research and development initiatives.
- Membrane separation processes and chemical process engineering need to be reorganized as science and technology move forward.[20–23]

1.17 Conclusion, Summary and Scientific Perspectives

Technological vision, scientific vision and scientific validation are major needs of human scientific endeavor today. Scientific perspectives in the field of environmental protection and environmental remediation are changing and need to be restructured as science and technology move forward towards a new visionary era. The intricate questions of environmental and energy sustainability are still unanswered today. The authors have depicted in detail the success and the vision of science and the wide domain of scientific validation in environmental engineering science. Technology and engineering science today have no answers to the intricate issues of arsenic and heavy metal groundwater contamination. The authors have specifically focused on the great scientific ingenuity and depth in nanotechnology applications in environmental remediation. Other areas include deliberations in the field of conventional and non-conventional environmental engineering tools. Successes have been achieved in the field of membrane science and desalination. Humans' impressive visionary scientific endeavors, the futuristic vision of environmental protection science and the world of desalination will surely open up a new scientific understanding and new scientific truths in the domains of chemical process engineering and environmental engineering. Technology and engineering science are facing great challenges as environmental disasters, the technological hiatus and the ever-growing concerns about global climate change and the loss of ecological biodiversity are major problems for the scientific community. The authors forcefully take up this challenge to reorganize the scientific vision of environmental remediation and environmental engineering. The scientific perspectives in the field of non-conventional environmental engineering techniques such as advanced oxidation processes need to be widely reorganized. This chapter opens up new thoughts for the future and presents new scientific ideals in the global environmental engineering scenario. The world of science and technology will witness new emancipation and new scientific regeneration in the decades to come.

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CHAPTER 2

Hazardous Wastes – Types and Sources

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2.1 Introduction

All around the globe, the economic and social status of people is changing very rapidly. Especially in developing countries, the need for a better economic state is a prerequisite for better social status. The economic growth and development of a country result in many adverse effects on the environment, *viz.* waste generation, greenhouse gas emissions, deforestation, land degradation, *etc.* Waste can be described in the most characteristic way as unwanted material generated in any production process. Although the definition of waste and its categorization may vary slightly in different countries, waste and waste management represent a significant global issue. The never-ending race towards urbanization and modern lifestyle to become a developed country has a serious disadvantage, namely the generation of hazardous waste. With a paradigm shift in economy with the goal of industrialization, the number of industries, particularly those which produce

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hazardous wastes, has increased dramatically. During the past few decades, the generation of hazardous waste has increased alarmingly around the globe[1–3] and there is an urgent need to develop comprehensive strategies for hazardous waste management. In order to do so, proper guidelines, classification practices and the promotion of reuse and recycling need to be developed. Hazardous waste accounted for about half of the environmental consultation market worth $8.2 billion in 1991,[4] which makes it very evident that hazardous waste was also of great significance nearly 30 years ago. What makes it so concerning is its toxicity, which is why the scientific and practical definition of hazardous waste and its proper treatment and disposal have been dominant over other environmental issues. This chapter attempts to address these issues and provide a comprehensive strategy for the storage, treatment and proper disposal of hazardous waste.

2.2 Management of Hazardous Waste

Initially, officials around the globe were not concerned about the consequences of hazardous waste for environmental and human health. Gradually, with the advances and developments in science and the advent of many interdisciplinary fields, researchers across the world started to recognize the looming threat of chemicals and the consequences for society. Accident episodes were now increasingly associated with chemicals and these accidents attracted attention throughout the world, hence a need to define hazardous waste became evident.

2.2.1 Identification and Classification

Various countries have their own classification system pertaining to hazardous waste and there are multiple levels of sophistication and complexities involved in the identification of hazardous waste. Therein lies a very basic difficulty for government and industrial organizations engaged in hazardous waste control programs, namely to define hazardous waste realistically within the scientific and practical domains. Correct identification and subsequent classification are essential to ensure that the collection, transportation, storage, and treatment of waste and its proper disposal are carried out in a manner that not only protects human health but also provides protection for the environment, and in compliance with legal requirements. This chapter presents the classification system adopted by United States Environmental Protection Agency (EPA) and also by the European Union Environmental Protection Agency, which is accepted across the European Union.

First, correct classification depends mostly on correct identification, and to address this issue the Resource Conservation and Recovery Act (RCRA) describes the four steps necessary for preliminary identification of hazardous waste.[5] These steps are summarized in Figure 2.1. Moreover, the RCRA[5] defines hazardous waste as "a solid waste or combination of solid waste, which because of its quantity, concentration or physical, chemical or

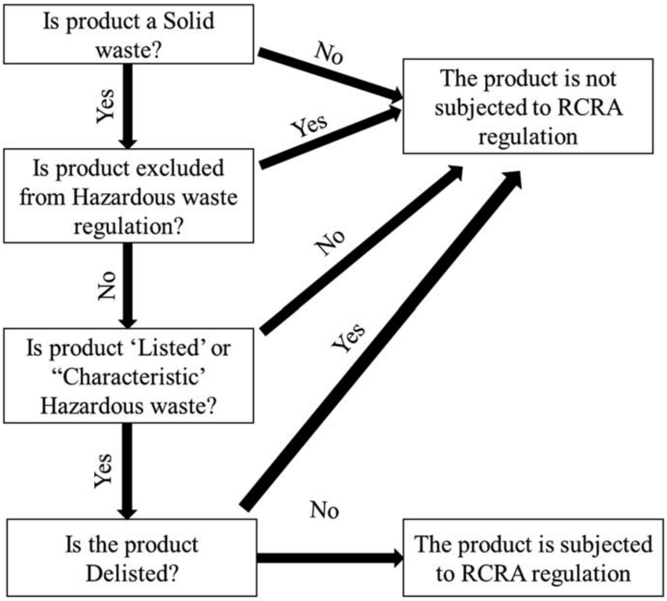

Figure 2.1 Identification process for hazardous waste. See also ref. 5.

infectious characteristics may (a) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible, illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of or otherwise managed''. This classification is based on the fact that ''such wastes are non-degradable or persistent in nature or they can be biologically magnified or because they can be lethal or because they may otherwise cause or tend to cause detrimental cumulative effects''.[6]

The definition provided by the RCRA is very broad one and does not clearly indicate the threats posed by the waste(s). This issue was therefore addressed by classifying the waste through (1) listing of hazardous wastes and (2) identification of certain specific characteristics which, when present in a waste, makes it hazardous.

2.2.1.1 *Listed Hazardous Waste*

Hazardous waste listings by the EPA specifically describe the specific types of waste that are dangerous enough to warrant regulatory action. Hence it becomes very important that, before the final listing, the EPA conducts comprehensive studies regarding threats posed by a particular waste and waste stream to human and environmental health. If a waste or stream is found to be threatening enough, it can be listed in one of the lists and be classified as hazardous. Thereafter, any waste that conforms to the listing criteria is considered hazardous, regardless of its chemical composition or any such variable. The four criteria that the EPA may use to list a waste are as follows:

1. The waste typically contains harmful chemicals and other factors indicate that it could pose a threat to human health and the environment in the absence of special regulation. Such wastes are known as toxic listed wastes.
2. The waste contains such dangerous chemicals that it could pose a threat to human health and the environment even when properly managed. Such wastes are known as acutely hazardous wastes.
3. The waste typically exhibits one of the four characteristics of hazardous waste described in the hazardous waste identification regulations (ignitability, corrosivity, reactivity or toxicity).
4. When the EPA has to cause to believe for some other reason that the waste typically fits within the statutory definition of hazardous waste developed by Congress.

The EPA may list any waste using one or more of the criteria mentioned above. Based on these, four lists were prepared by the EPA, with each list designating from about 30 to a few hundred waste streams as hazardous. Each waste is assigned a waste code consisting of the letter associated with the list followed by three digits. For example, the wastes on the F list are assigned the waste codes F001, F002 and so on. The four lists prepared by the EPA are as follows:[5]

- *The F list:* since the processes producing industrial solid waste vary greatly across the sectors, the F list wastes are considered to be wastes from non-specific sources. The list designates particular solid wastes from certain common industrial or manufacturing processes as hazardous. The F list is codified in the regulations at §261.31.
- *The K list:* the K list labels a particular solid waste from certain specific industries. Wastes in this list are known as wastes from specific sources. The K list is found at §261.32.
- *The P and the U lists:* these two lists are similar in the sense that both have listings of pure or commercial grade formulations of certain specific unused chemicals as hazardous. Both the P and U lists are codified in §261.33.

2.2.1.2 Characteristic Hazardous Waste

Successful identification and subsequent classification are mainly governed by some characteristic features and these sets of characteristic feature can very well be used to classify hazardous waste. Even though unanimous definitions of hazardous waste have not been formulated across the globe, there is a universal acceptance towards these characteristic features. According to the EPA,[7] if a substance shows one or many of the following characteristics upon self-reaction or reaction with other compounds, it may be classified as a hazardous substance. These characteristic features are defined as follows:[5]

1. *Ignitability:* Any waste product that can create fire under certain conditions, has a flash point of less than 60 °C and shows spontaneous combustible characteristics can be called an ignitable product.
2. *Corrosivity:* All the acids or bases ($2 \leq pH \geq 12.5$) and/or any waste product that are capable of causing corrosion in metal containers (such as storage tanks, drums, *etc.*).
3. *Reactivity:* If any material is unstable under normal conditions, it can be considered a reactive hazardous waste. "These products may cause explosions, undergo violent reactions, generate toxic fumes, gases or vapors or explosive mixtures when heated, compressed or mixed with water".[5]
4. *Toxicity:* A waste product is referred to as toxic when its proven to be harmful or fatal upon ingestion or adsorbed. Determination of toxicity is carried out through a laboratory test known as the "Toxicity Characteristic Leaching Procedure" (TCLP).

2.2.1.3 Wastes Listed Solely for Exhibiting the Characteristic of Ignitability, Corrosivity and/or Reactivity

The regulation of wastes listed solely for exhibiting the characteristic of ignitability, corrosivity and/or reactivity does not work in the same way as that of other listed hazardous wastes under RCRA. Hence, according to RCRA (66 FR 27266), "When wastes are generated that meet a listing description for one of the 29 wastes listed only for exhibiting the characteristic of ignitability, corrosivity and/or reactivity, the waste is not hazardous if it does not exhibit a characteristic".[9]

2.2.1.4 The Mixture and Derived-from Rules

Through the listing of hazardous waste and characterization, most of the bases for identification of such wastes were considered to be covered. However, some key concerns were subsequently raised regarding the identification process. One such concern was "what if the hazardous waste is changed chemically or physically in some way, will it still be considered hazardous?" To resolve this issue, the EPA quickly came up with a very simple and strict guideline. This guideline was broadly presented in mixture and derived-from rules. These rules operate differently for listed and characteristic hazardous wastes.

2.2.1.4.1 Listed Hazardous Waste. The mixture rule for listed wastes states that "a mixture made up of any amount of a non-hazardous solid waste and any amount of a listed hazardous waste is considered a listed hazardous waste. In other words, if a small vial of listed waste is mixed with a large quantity of non-hazardous waste, the resulting mixture bears the same waste code and regulatory status as the original listed component of the mixture''. Similarly, the derived-from rule for listed wastes states that ''any material derived from a listed hazardous waste is also a listed hazardous waste. Thus, ash produced by burning a listed hazardous waste bears the same waste code and regulatory status as the original listed waste, regardless of the ash's actual properties''.[5]

2.2.1.4.2 Characteristic Wastes. As mentioned earlier, norms for listed waste and characteristic wastes are different. The EPA decided that since the waste mixture does not exhibit any of the four characteristics, it shall no longer be considered hazardous. Hence ''a mixture involving characteristic wastes is hazardous only if the mixture itself exhibits a characteristic. Similarly, treatment residues and materials derived from characteristic wastes are hazardous only if they themselves exhibit a characteristic''.[5]

2.2.1.4.3 Waste Listed Solely for Exhibiting the Characteristic of Ignitability, Corrosivity and/or Reactivity. It is mentioned that ''if a hazardous waste listed only for the characteristics of ignitability, corrosivity and/or reactivity is mixed with a solid waste, the original listing does not carry through to the resulting mixture if that mixture does not exhibit any hazardous waste characteristics''.[5] Similarly, for derived-from it states that ''if a waste derived from the treatment, storage or disposal of a hazardous waste listed for the characteristics of ignitability, corrosivity and/or reactivity no longer exhibits one of those characteristics, it is not a hazardous waste''.[5]

Another major guideline (valid from 2015) followed across the European Union is given by the Environmental Protection Agency (EPA) Ireland, which mentions two very critical elements for hazardous waste classification:[5]

1. Preparation of List of Waste (LoW): ''The LoW provides a harmonized list for coding all waste. The different types of waste in the list are fully defined by the six-digit entry for the waste including the respective two-digit and four-digit chapter headings''.[8]

   As per the LoW, waste can be categorized in any one of the following three entry types:
   (i) non-hazardous;
   (ii) hazardous (marked with an asterisk);
   (iii) mirror – either hazardous or non-hazardous.

   One very important and notable point here is that, without any prejudice, if a waste has been entered in a non-hazardous category, no further assessment is required and the entry is finalized as non-hazardous. Similarly, if a waste has been entered in a hazardous category, it is hazardous without any further assessment. However,

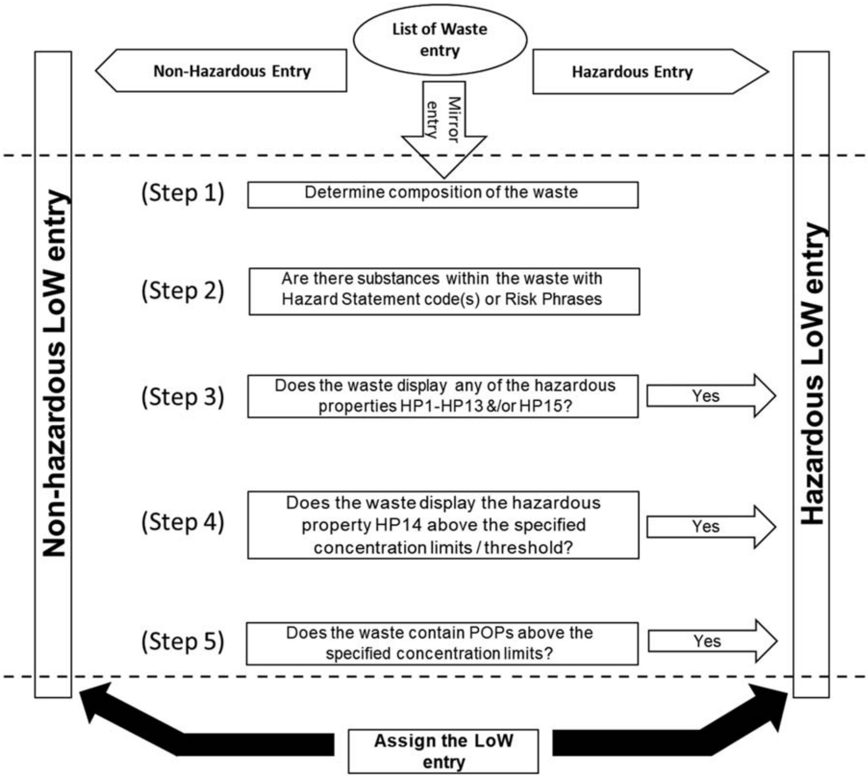

Figure 2.2 Steps for determination of hazardous waste entry. Reproduced with permission from: EPA Ireland.[8]

provisions and directives are in place to rectify any entry based on evidence.

Moreover, if the list has a mirror entry, it is dealt with in accordance with the second element:

2. Determining if waste is hazardous or non-hazardous: "If the waste has a mirror entry, it must be subject to further assessment to determine if it is hazardous or not". The necessary steps are outlined in Figure 2.2.

Various classes of hazardous waste and a few examples are compiled in Table 2.1.[10,11] This table illustrates the similarity between UN class number and EPA identification number of hazardous waste classification.

2.2.1.5 Tests for Hazardous Wastes

Various physical and chemical tests are required to identify several waste characteristics so that optimum and efficient treatment and disposal guidelines can be formulated. These test method numbers, listed by the

Table 2.1 Various classes of hazardous waste with EPA Ireland identification number.

UN class number (1989)	Characteristics	Types	Examples	Similar EPA identification number
1	Explosives	Projection, mass explosion, minor hazard	Ammonium perchlorate, cyclonite, explosive articles	D003
2	Gases	Poisonous, flammable gas, non-flammable gas	Compressed oxygen, butane, ammonia	D001
3, 4	Flammable solids and liquids	Low flash point range, medium flash range, high flash range	Acetone, alcohol, diethyl ether	D001
		Flammable solids, spontaneous combustion, emitting flammable gases when wet	White phosphorus, yellow phosphorus, alkali metals	
5	Oxidizing substances	Oxidizing compounds of all types	Sodium peroxide, potassium permanganate, potassium superoxide	D002
6	Infectious substances	Poisonous agents, infectious agents	Arsenic, clinical waste	D003
7	Radioactive materials	Radioactive compounds of all kinds	Uranium	D003
8	Corrosives	Corrosive in nature	Mineral acids, organic acids, strong bases	D002
9	Toxic	Toxic to the ecosystem or society	Environmentally hazardous chemicals	D004–D043

EPA,[12] are summarized in Table 2.2. The choice of appropriate method depends upon the detail of the information sought for final treatment/disposal. Moreover, to choose the correct method, some basic information is necessary, which includes the following:

1. Physical state of the sample: aqueous, solid, volatile, sludge, multiphase sample.
2. Analytes of interest: organic (carbon compounds) or inorganic (metals and anions).
3. Analytical sensitivity required.
4. Analytical objective: screening methods/composite sampling, *etc.*
5. Purpose of testing: quantitation or monitoring.
6. Information regarding sample containers and holding time.

Table 2.2 Applicable method numbers for various tests of hazardous waste.

Applicable determinative method numbers for:		
Organic analyses	Inorganic analyses	Miscellaneous methods
8000D, 8011, 8015C, 8021B, 8031, 8032A, 8033, 8041A, 8061A, 8070A, 8081B, 8082A, 8085, 8091, 8095, 9100, 8111, 8121, 8131, 8141B, 8151A, 8260B, 8261, 8270D, 8275A, 8276, 8280B, 820A, 8310, 8315A, 8316, 8318A, 8321B, 8325, 8330A, 8331, 8332, 8410, 8430, 8440, 8520	6010D, 6020B, 6200, 6500, 6800, 7000B, 7010, 7061A, 7062, 7063, 7195, 7196A, 7197, 7198, 7199, 7470A, 7471B, 7472, 7473, 7474, 7580, 7741A, 7742	5050, 9000, 9001, 9010C, 9012B, 9013A, 9014, 9015, 9016, 9020B, 9021, 9022, 9023, 9030B, 9031, 9034, 9035, 9036, 9038, 9056A, 9057, 9060A, 9065, 9066, 9067, 9070A, 9071B, 9075, 9076, 9077, 9131, 9132, 9210A, 9211, 9212, 9213, 9214, 9215, 9216, 9250, 9251, 9253, 9320

2.3 Waste Generators

A waste generator may be any person who produces a hazardous waste. As the quantity of generated waste may vary, the EPA has categorized generators in three different categories, based on the quantity of hazardous waste generated each month,[13] as follows:

1. very small quantity generators (VSQGs);
2. small quantity generators (SQGs); and
3. large quantity generators (LQGs).

Identification of the generator category is essential for all of the generators. The criteria for determining the category are given in Table 2.3.

There are certain requirements for all waste generators, as described in 40 CFR Part 262,[13] and some of those regulations are as follows:

1. Very small quantity generators (VSQGs):
   - VSQGs must identify all the hazardous waste generated.
   - VSQGs may not accumulate more than 1000 kg of hazardous waste at any time.
   - VSQGs must ensure that hazardous waste is delivered to the authorized person or facility only.
2. Small quantity generators (SQGs):
   - SQGs may accumulate hazardous waste on-site for 180 days without a permit (or 270 days if shipping a distance greater than 200 miles).
   - The quantity of hazardous on-site waste must never exceed 6000 kg.
   - As SQGs are not required to have detailed contingency plans, there must always be at least one employee available to respond to an emergency, who is responsible for coordinating all emergency response measures.