Contents

1 Introduction 1
Scope 1
New Space Industries and Space Mining Ventures 2
What Natural Resources Are Found in Space and Where Are They? 3
The Technology 5
New Space and the Key Space Actors 5
The Legal and Regulatory Context: Today and Tomorrow 6
The Longer Term Perspective 7
Structure and Purpose of This Book 8

2 The Importance of Natural Resources from Space and Key Challenges 11
Gauging the Future 13
Coping with the Scale and Complexity Problem 15
Coping with Legal, Regulatory and Standards Problems 19
Conclusions 21

3 Transportation Systems and Targeting Locations for Space Mining 23
New and Improved Transportation Technologies to Support Space Mining 27
Chemical Fueled Launchers 27
Ion Propulsion 28
Nuclear Fueled Propulsion 29
Mass-Driver Systems on the Moon 31
Space Elevator Systems 31
Conclusions 32

4 Power and Robotic Systems for Space Mining Operations 33
Power Systems 34
Photovoltaic and Battery Systems 34
Space-Based Thermocouple Energy Systems 34
Nuclear or Radioactive Isotope Power System 35
Thermoionic Power Source 36
Explosives as a Substitute for Mining-Related Energy Needs 37

Space Robotic Mining Systems 37
Innovative New Space Mining Concepts 38
Conclusions 40

5 U. S. Space Exploration and Planetary Resources 41
Space Telescope Missions 41
The Apollo Lunar Exploration Program 42
The Mariners, MESSENGER, the Voyagers, Galileo, the Pioneers, Juno, Huygens-Cassini, Magellan and New Horizons 42
Lunar Missions 45
Mars Missions 47
NASA Asteroid Mission 50
Assessing the Broad Impact of U. S. Space Missions Over the Past Half Century 51
Space Telescope Findings 51
Useful Information about the Moon 52
Findings Related to Planetary Bodies 53
Mars Exploratory Programs 54
Missions to Comets and Asteroids 56
The Future of Space Exploration Technology Related to Space Mining 57
Conclusions 57

6 Private Sector Space Mining Initiatives and Policies in the United States 59
The Rapid Growth of New Space Activities in the United States 60
Planetary Resources 64
Deep Space Industries 65
Golden Spike Company 66
Shackleton Energy Company 68
Moon Express 69
The B612 Foundation 69
Policies Concerning Space Mining, Resource Extraction and Space Colonies 70
Conclusions 71

7 Space Enterprises in Russia and the Former Soviet Union 73
Conclusions 83

8 Activities in Europe, Canada and Other Western Countries 85
Herschel Space Observatory 85
Mars Express 86
Venus Express 88
Mercury Mission 88
Jupiter Exploratory Mission 88
European Mission to the Moon 89
ESA's Deep Space Missions: Giotto, Rosetta, and PLATO 90

Summary of European Initiatives 92
Canada and Other National Initiatives 92
Conclusions 97

9 Asian Space Programs: Japan, China and India 99
Japanese Space Exploration and Scientific Missions 100
China's Planetary Research and Exploration Programs 105
The Indian Space Program 107
Conclusions 110

10 The International Legal Framework 113
The 1967 Outer Space Treaty 116
The Common Interest Principle and Freedom of Exploration and Use of Outer Space 116
Prohibition of Appropriation of Outer Space and Celestial Bodies 120
Prohibition of Appropriation of Space Natural Resources 123
The 1979 Moon Agreement 127
Conclusion 129

11 National Space Laws and the Exploitation of Natural Resources from Space 131
The United States 134
The United Kingdom 138
The Russian Federation 140
Australia 141
Canada 142
India 143
Conclusions 143

12 Conclusions and the Way Forward 145

Appendix: Excerpts of Key International Space Treaties and Relevant U. S. Law 153
Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967) 153
Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968) 157
Convention on International Liability for Damage Caused by Space Objects (1972) 159
Convention on Registration of Objects Launched into Outer Space (1975) 162
Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979) 165
The United States: Space Resource Exploration and Utilization Act of 2015 172

Title IV: Space Resource Exploration and Utilization 172
"Chapter 513: Space Resource Commercial Exploration and Utilization 173
SEC. 403. Disclaimer of Extraterritorial Sovereignty 174

Glossary 175

Index 179