Contents

1 Introduction ........................................ 1
   Arthur Pecher and Jens Peter Kofoed
   1.1 Introduction ........................................ 1
   1.2 The Successful Product Innovation .................... 2
   1.3 Sketching WECs and Their Environment ...................... 3
   1.4 Rules of Thumb for Wave Energy ........................... 5
       1.4.1 The Essential Features of a WEC .................... 5
       1.4.2 Economic Rules of Thumb .......................... 6
       1.4.3 WEC Design Rules of Thumb ....................... 9
       1.4.4 Power Take-Off Rules of Thumb .................... 12
       1.4.5 Environmental Rules of Thumb ..................... 13
   References ................................................. 14

2 The Wave Energy Sector .................................... 17
   Jens Peter Kofoed
   2.1 Introduction ......................................... 17
   2.2 Potential of Wave Energy ............................... 19
   2.3 Wave Energy Converters .................................. 22
       2.3.1 History .............................................. 22
       2.3.2 Categorization of WEC’s ............................ 23
       2.3.3 Examples of Various WEC Types ..................... 24
       2.3.4 The Development of WECs ............................ 37
   2.4 Test Sites ............................................. 39
   References ................................................. 41

3 The Wave Energy Resource .................................. 43
   Matt Folley
   3.1 Introduction to Ocean Waves ............................. 43
       3.1.1 Origin of Ocean Waves .............................. 43
       3.1.2 Overview of the Global Wave Energy Resource ........ 45

References......................................................................................................................... 47
## Water Wave Mechanics

### 3.2.1 Definition and Symbols

### 3.2.2 Dispersion Relationship

### 3.2.3 Water Particle Path and Wave Motions

## Characterisation of Ocean Waves and the Wave Climate

### 3.3.1 Introduction

### 3.3.2 Temporal, Directional and Spectral Characteristics of the Wave Climate

### 3.3.3 Spectral Representation of Ocean Waves

### 3.3.4 Characterization Parameters

### 3.3.5 Challenges in Wave Climate Characterisation

### 3.3.6 Coastal Processes

### 3.3.7 Case Study—Incident Wave Power

## Measurement of Ocean Waves

### 3.4.1 Overview

### 3.4.2 Surface-Following Buoy

### 3.4.3 Sea-Bed Pressure Sensor

### 3.4.4 Acoustic Current Profiler

### 3.4.5 Land-Based and Satellite Radar

## Modelling of Ocean Waves

### 3.5.1 Introduction

### 3.5.2 General Spectral Wave Models

### 3.5.3 Third Generation Spectral Wave Models

### 3.5.4 Grid Definition

## Techno-Economic Development of WECs

### 4.1 Introduction

### 4.1.1 Continuous Evaluation of the WEC Potential

### 4.1.2 Overview of the Techno-Economic Development

### 4.2 The WEC Development Stages

### 4.3 Techno-Economic Development Evaluation

### 4.3.1 The Technology Readiness and Performance Level

### 4.3.2 The WEC Development Stages and the TRL Scale

### 4.3.3 The TRL-TPL R&D Matrix

### 4.3.4 Uncertainty Related to the TRL-TPL Matrix

### 4.3.5 Valuation of R&D Companies

### 4.4 Techno-Economic Development Strategies

### 4.4.1 R&D Strategy as TRL-TPL Trajectories

### 4.4.2 Extreme Cases of Techno-Economic Development Strategy

### 4.4.3 Efficient Techno-Economic Development

## References
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>Conclusion</td>
<td>97</td>
</tr>
<tr>
<td>4.6</td>
<td>Overview of Some of the Leading WECs</td>
<td>98</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>98</td>
</tr>
<tr>
<td>5</td>
<td>Economics of WECs</td>
<td>101</td>
</tr>
<tr>
<td>Ronan Costello and Arthur Pecher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>101</td>
</tr>
<tr>
<td>5.2</td>
<td>Power Is Vanity—Energy Is Sanity</td>
<td>102</td>
</tr>
<tr>
<td>5.3</td>
<td>Economic Decision Making</td>
<td>103</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Cash Flow Terminology</td>
<td>104</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Time Value of Money (and Energy)</td>
<td>105</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Economic Metrics</td>
<td>106</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Effect of Depreciation on Discounting</td>
<td>112</td>
</tr>
<tr>
<td>5.3.5</td>
<td>Effect of Inflation on Discounting</td>
<td>112</td>
</tr>
<tr>
<td>5.3.6</td>
<td>Setting the Discount Rate</td>
<td>113</td>
</tr>
<tr>
<td>5.3.7</td>
<td>Economic Decision Making—Which Metric to Use?</td>
<td>114</td>
</tr>
<tr>
<td>5.3.8</td>
<td>Expert Oversight and Independent Review</td>
<td>116</td>
</tr>
<tr>
<td>5.4</td>
<td>Economic Analysis in Technology R&amp;D</td>
<td>117</td>
</tr>
<tr>
<td>5.5</td>
<td>Techno-Economic Assessment and Optimisation</td>
<td>118</td>
</tr>
<tr>
<td>5.6</td>
<td>WEC Cost-of-Energy Estimation Based on Offshore Wind Energy Farm Experience</td>
<td>119</td>
</tr>
<tr>
<td>5.6.1</td>
<td>Introduction</td>
<td>119</td>
</tr>
<tr>
<td>5.6.2</td>
<td>Definition of the Categories</td>
<td>120</td>
</tr>
<tr>
<td>5.6.3</td>
<td>Wind Energy Project Case</td>
<td>121</td>
</tr>
<tr>
<td>5.6.4</td>
<td>Wave Energy Case</td>
<td>124</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Cost Reduction</td>
<td>131</td>
</tr>
<tr>
<td>5.6.6</td>
<td>Revenue and Energy Yield</td>
<td>133</td>
</tr>
<tr>
<td>5.7</td>
<td>Strategic Support Mechanisms</td>
<td>133</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>135</td>
</tr>
<tr>
<td>6</td>
<td>Hydrodynamics of WECs</td>
<td>139</td>
</tr>
<tr>
<td>Jørgen Hals Todalshaug</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>Introduction</td>
<td>139</td>
</tr>
<tr>
<td>6.1.1</td>
<td>Wave Energy Absorption is Wave Interference</td>
<td>139</td>
</tr>
<tr>
<td>6.1.2</td>
<td>Hydrostatics: Buoyancy and Stability</td>
<td>140</td>
</tr>
<tr>
<td>6.1.3</td>
<td>Hydrodynamic Forces and Body Motions</td>
<td>143</td>
</tr>
<tr>
<td>6.1.4</td>
<td>Resonance</td>
<td>146</td>
</tr>
<tr>
<td>6.1.5</td>
<td>Oscillating Water Columns—Comments on Resonance Properties and Modelling</td>
<td>147</td>
</tr>
<tr>
<td>6.1.6</td>
<td>Hydrodynamic Design of a Wave Energy Converter</td>
<td>149</td>
</tr>
<tr>
<td>6.1.7</td>
<td>Power Estimates and Limits to the Absorbed Power</td>
<td>153</td>
</tr>
<tr>
<td>6.1.8</td>
<td>Controlled Motion and Maximisation of Output Power</td>
<td>156</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>157</td>
</tr>
</tbody>
</table>
7 Mooring Design for WECs ........................................ 159
Lars Bergdahl

7.1 Introduction ...................................................... 159
7.1.1 General ...................................................... 159
7.1.2 Mooring Design Development Overview ................. 160
7.1.3 Wave-Induced Forces on Structures ..................... 162
7.1.4 Motions of a Moored Device in Waves ................. 162

7.2 Metocean Conditions .......................................... 162
7.2.1 Combinations of Environmental Conditions .......... 162
7.2.2 Design Wave Conditions .................................. 163
7.2.3 Environmental Data at DanWEC ......................... 165
7.2.4 Example Design Conditions ............................. 166

7.3 Estimation of Environmental Forces ....................... 166
7.3.1 Overview and Example Floater Properties ............ 166
7.3.2 Mean Wind and Current Forces ......................... 167
7.3.3 Wave Forces .............................................. 169
7.3.4 Summary of Environmental Forces on Buoy .......... 178

7.4 Mooring System Static Properties .......................... 179
7.4.1 Example ..................................................... 179
7.4.2 Catenary Equations ..................................... 180
7.4.3 Mean Excursion .......................................... 182

7.5 Alternative Design Procedures .............................. 183
7.5.1 Quasi-Static Design ...................................... 183
7.5.2 Dynamic Design .......................................... 187
7.5.3 Response-Based Analysis .............................. 188

7.6 Response Motion of the Moored Structure ................ 189
7.6.1 Equation of Motion ....................................... 189
7.6.2 Free Vibration of a Floating Buoy in Surge .......... 190
7.6.3 Response to Harmonic Forces .......................... 191
7.6.4 Response Motion in Irregular Waves ................... 194
7.6.5 Equivalent Linearized Drag Damping ................... 196
7.6.6 Second-Order Slowly Varying Motion .................. 197
7.6.7 Wave Drift Damping .................................... 198
7.6.8 Combined Maximum Excursions ....................... 198

7.7 Conclusions ..................................................... 199

References ............................................................. 200

8 Power Take-Off Systems for WECs ............................. 203
Amélie Tétu

8.1 Introduction, Importance and Challenges .................. 203
8.2 Types of Power Take-Off System ............................ 205
8.2.1 Overview .................................................. 205
8.2.2 Air Turbines .............................................. 206
8.2.3 Hydraulic Converters .................................... 210
Handbook of Ocean Wave Energy
Pecher, A.; Kofoed, J.P. (Eds.)
2017, XXI, 287 p. 152 illus., 85 illus. in color., Hardcover
ISBN: 978-3-319-39888-4