Fabrication Market Outlook
# Table of Contents

## Executive Summary
- Essay: How Fabrication Fits Into the Bigger Fuel Picture ................................................................. i
- Reactor Developments and LWR Fuel Demand Forecasts ........................................................................... i
- UxC Utility Fabrication Market Survey ....................................................................................................... ii
- The World’s LWR Nuclear Fuel Fabricators ............................................................................................... ii
- Supply and Demand in the Nuclear Fuel Fabrication Industry ................................................................. iii
- LWR Nuclear Fuel Fabrication Markets ..................................................................................................... iii
- LWR Nuclear Fuel Fabrication Prices ........................................................................................................ iv
- Non-LWR Fuel Fabrication Markets .......................................................................................................... iv

## Introduction and Overview
- What’s New in the 2019 Report? ................................................................................................................. 10
  - FMO Reference Document ......................................................................................................................... 13
- Structure of Report ....................................................................................................................................... 13

## 1 – Essay: How Fabrication Fits Into the Bigger Fuel Picture
- Nuclear Fuel’s Role in Nuclear Power Operations ...................................................................................... 15
  - U.S. Nuclear Reactor Fleet Data .................................................................................................................. 15
- Fuel Fabrication’s Role in the Front-End Fuel Cycle ................................................................................... 18
  - How is Fabrication Different? ..................................................................................................................... 18
    - Fabrication Procurement Separated from Other Fuel Components ......................................................... 18
  - Fabrication Deliveries Mainly Just-In-Time ............................................................................................... 18
  - Utility Views on Fabrication Procurement Costs ....................................................................................... 19
  - Fabrication as Percent of Total Fuel Costs .................................................................................................. 19
- Utility Views on Specific Fabrication Vendors ........................................................................................... 20
  - Views on Framatome ................................................................................................................................. 20
  - Views on Westinghouse ............................................................................................................................. 20
  - Views on TVEL ........................................................................................................................................... 21
- Future Utility Fabrication Procurement Trends .......................................................................................... 21
  - Promoting New Fuel Designs and Vendors ............................................................................................... 21
  - Higher Burnup Fuel .................................................................................................................................. 22
  - Accident Tolerant Fuel (ATF) .................................................................................................................... 23
    - Brief Update on Latest ATF Developments ............................................................................................. 23
    - Utility Views on ATFs and Future Commercialization ........................................................................ 25
      - Are You Considering Using ATFs? .......................................................................................................... 25
      - Biggest Challenges for ATF Deployment .............................................................................................. 25
      - Timeframe for ATF Commercialization .............................................................................................. 26

## Conclusions .................................................................................................................................................. 27

## 2 – Reactor Developments and Demand Outlook
- UxC Nuclear Power Regions ......................................................................................................................... 28
- Reactor Capacities Anticipated by Country by 2035 .................................................................................. 29
- Alternative UxC Reactor Forecast Cases ..................................................................................................... 30
- Current and Future Reactor Types ................................................................................................................ 33
  - Currently Operating Reactors ..................................................................................................................... 34
  - New Reactors .............................................................................................................................................. 34
    - New Reactor Types .................................................................................................................................. 35
    - New Reactor Vendors ............................................................................................................................... 36
- Fuel Fabrication Demand Forecasts ............................................................................................................ 38
  - UxC Fabrication Market Demand Modeling .............................................................................................. 38
    - UxC Requirements Model (URM) ............................................................................................................ 38
    - Use of URM Fabrication Demand Forecasts ......................................................................................... 38
  - UxC Fabrication Demand Forecasts ........................................................................................................ 39
    - Global LWR Fuel Fabrication Requirements .......................................................................................... 39
    - Regional LWR Fuel Fabrication Requirements ..................................................................................... 40
    - LWR Fabrication Requirements by Fuel Type ....................................................................................... 41
### Table of Contents

**3 – Results from UxC Utility Fabrication Market Survey**

- Conclusions from Demand Analysis ........................................................................................................... 42
- State of the Market ................................................................................................................................. 43
- Cycle Length ........................................................................................................................................... 44
- New Contract Scope ............................................................................................................................. 44
- Procurement Lead Time ......................................................................................................................... 45
- Procurement Approach ......................................................................................................................... 45
- Vendor Qualification ............................................................................................................................. 46
- Adequacy of Competition ..................................................................................................................... 46
- Vendors Declining to Bid ...................................................................................................................... 47
- Fuel Delivery Schedules and Inventories ............................................................................................... 47
- Scope of Services Under Fuel Supply Contracts .................................................................................. 48
- Consistency of Supply ........................................................................................................................... 48
- Acceptance of New Designs from Established Suppliers ....................................................................... 49
- Fuel Contracting Criteria ...................................................................................................................... 49
- Major Industry Trends .......................................................................................................................... 50
- Conclusions from Utility Survey ........................................................................................................... 51
- Lessons Learned .................................................................................................................................... 52

**4 – The World’s Nuclear Fuel Fabricators**

- The Mega-Vendors .................................................................................................................................. 53
  - Framatome ............................................................................................................................................. 55
    - Framatome Emerges from AREVA .................................................................................................. 55
    - Impact on Framatome’s Fuel Fabrication Business ......................................................................... 56
    - Ownership and Organization ........................................................................................................... 56
    - Ownership ....................................................................................................................................... 56
    - Current Organization ....................................................................................................................... 56
    - Fuel Business Unit (FBU) Overview .................................................................................................. 57
    - European Fuel Fabrication Operations ............................................................................................ 57
    - Production Facilities .......................................................................................................................... 57
    - Markets and Products ....................................................................................................................... 58
      - TVEL Fuel Company Subcontract ................................................................................................. 59
      - Framatome’s Fuel Assembly Designs ........................................................................................... 60
    - U.S. Fuel Fabrication Operations ...................................................................................................... 63
      - Production Facilities ....................................................................................................................... 63
      - Markets and Products ..................................................................................................................... 63
      - Accident Tolerant Fuel and Advanced Fuel Developments ........................................................... 64
      - Enfission Joint Venture with Lightbridge ...................................................................................... 64
    - Japanese Fuel Fabrication Operations .............................................................................................. 65
    - Chinese Fuel Fabrication Operations ............................................................................................... 65
    - Kazakh Fuel Fabrication Operations ............................................................................................... 66
    - Comprehensive Fuel Offerings .......................................................................................................... 66
    - Possible Future Developments .......................................................................................................... 66
  - Global Nuclear Fuel (GNF) .................................................................................................................... 68
    - Ownership and Organization ............................................................................................................ 68
    - U.S. and European Fuel Fabrication Operations .............................................................................. 68
      - Production Facilities ....................................................................................................................... 68
      - Markets and Products ..................................................................................................................... 69
        - Strategic Alliance with TVEL Fuel Company ............................................................................... 70
      - GNF’s Fuel Assembly Designs ....................................................................................................... 70
      - Accident Tolerant Fuel Developments ......................................................................................... 72
    - Japanese Fuel Fabrication Operations .............................................................................................. 73
      - Production Facilities ....................................................................................................................... 73
      - Markets and Products ..................................................................................................................... 74
      - Comprehensive Fuel Offerings ....................................................................................................... 75
      - Possible Future Developments ....................................................................................................... 75
  - Westinghouse Electric Company .......................................................................................................... 76
    - Ownership and Organization ............................................................................................................ 76
    - Ownership ....................................................................................................................................... 76
    - Organization .................................................................................................................................... 77
Table of Contents

- Regional Organizations ........................................................................................................ 77
- Westinghouse Nuclear Fuel Division Overview .................................................................... 78
- Agreements and Joint Ventures with Foreign Suppliers ......................................................... 79

European Fuel Fabrication Operations.................................................................................. 80
- Westinghouse Electric Sweden, Västerås Nuclear Fuel Factory ............................................. 80
- Springfields Fuels, Ltd. – Preston, Lancashire, UK ................................................................. 81
- Markets and Products ............................................................................................................. 82

U.S. Fuel Fabrication Operations............................................................................................ 83
- Columbia Fuel Fabrication Facility ....................................................................................... 83
- Scrubber Incident in 2016 ....................................................................................................... 84
- Uranium Solution Leak in 2018 ............................................................................................ 84
- Radioactive Waste Container Leak in 2019 .......................................................................... 85
- Windsor Fuel Components Facility ....................................................................................... 85
- Markets and Products ............................................................................................................. 85
- Westinghouse Fuel Assembly Designs .................................................................................. 86
- Accident Tolerant Fuel Developments .................................................................................. 89

VVER Fuel Fabrication Operations.......................................................................................... 90
- VVER-1000 ............................................................................................................................ 90
- VVER-440 .............................................................................................................................. 92

Chinese Fuel Fabrication Operations...................................................................................... 93
- Comprehensive Fuel Offerings ............................................................................................. 93
- Possible Future Developments ............................................................................................. 94

Emerging International Suppliers............................................................................................. 95
- TVEL Fuel Company (TVEL) ................................................................................................... 95
  - Ownership and Organization ................................................................................................. 95
  - Production Facilities ............................................................................................................ 98
    - MSZ – Elektrostal ................................................................................................................ 98
      - Production Capacity .......................................................................................................... 99
      - MSZ Fuel Designs ............................................................................................................. 99
      - Modernization Program .................................................................................................... 100
    - NCCP – Novosibirsk ......................................................................................................... 101
  - Plans for Expanding Fabrication Capability .................................................................... 102
  - Consolidation of TVEL Fabrication Activities ................................................................ 103
  - Technical and Engineering Support ................................................................................. 103
  - Past, Present, and Future Markets ..................................................................................... 104
    - VVER Fuel Markets ........................................................................................................... 104
    - PHWR Fuel Market ............................................................................................................ 107
    - BWR and PWR Fuel Markets ............................................................................................ 107
      - Framatome Subcontract .................................................................................................... 107
      - TVS-KVADRAT – TVEL’s PWR Reload Fuel Initiative ..................................................... 108
  - TVEL Technology and Fuel Designs .................................................................................. 109
    - VVER-440 Fuel Assemblies .............................................................................................. 110
    - VVER-1000 Fuel Assemblies ............................................................................................ 112
    - Western PWR Fuel Assemblies ....................................................................................... 116
    - Accident Tolerant Fuel Developments .......................................................................... 116
  - Possible Future Developments ........................................................................................... 117

- KEPCO Nuclear Fuel (KNF) .................................................................................................... 118
  - Ownership and Organization ............................................................................................. 118
  - Fuel Fabrication Operations .............................................................................................. 118
  - Current and Future Markets ............................................................................................... 121
    - Domestic Market ............................................................................................................... 121
    - Foreign Markets ............................................................................................................... 121
  - KNF Fuel Designs ................................................................................................................ 123
  - Comprehensive Fuel Offerings ........................................................................................... 124
  - Possible Future Developments ........................................................................................... 125

Regional and National Fuel Suppliers .................................................................................... 127
- ENUSA Industrias Avanzadas, S.A. (ENUSA) – Spain .......................................................... 128
  - Ownership and Organization ............................................................................................. 128
  - Fuel Fabrication Operations – Juzbado Nuclear Fuel Factory ............................................. 129
  - Current and Future Markets ............................................................................................... 130
    - Spanish Market .................................................................................................................. 130
    - Foreign Markets ............................................................................................................... 131
  - ENUSA Fuel Assembly Designs .......................................................................................... 132
  - Comprehensive Fuel Offerings ........................................................................................... 133
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible Future Developments</td>
<td>133</td>
</tr>
<tr>
<td>• Editor’s Note on Japan</td>
<td>134</td>
</tr>
<tr>
<td>Potential Consolidation</td>
<td>134</td>
</tr>
<tr>
<td>• Mitsubishi Nuclear Fuel (MNF) – Japan</td>
<td>135</td>
</tr>
<tr>
<td>Ownership and Organization</td>
<td>135</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>136</td>
</tr>
<tr>
<td>Japanese Operations – Tokai-mura Works</td>
<td>136</td>
</tr>
<tr>
<td>Foreign Operations</td>
<td>137</td>
</tr>
<tr>
<td>Current and Future Markets</td>
<td>137</td>
</tr>
<tr>
<td>Japanese Market</td>
<td>137</td>
</tr>
<tr>
<td>Foreign Markets</td>
<td>138</td>
</tr>
<tr>
<td>MNF Fuel Designs</td>
<td>138</td>
</tr>
<tr>
<td>Domestic Designs</td>
<td>138</td>
</tr>
<tr>
<td>US-APWR Fuel Assembly</td>
<td>139</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>141</td>
</tr>
<tr>
<td>• Nuclear Fuel Industries (NFI) – Japan</td>
<td>142</td>
</tr>
<tr>
<td>Ownership and Organization</td>
<td>142</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>142</td>
</tr>
<tr>
<td>Current and Future Markets</td>
<td>143</td>
</tr>
<tr>
<td>Japanese Market</td>
<td>143</td>
</tr>
<tr>
<td>Foreign Markets</td>
<td>143</td>
</tr>
<tr>
<td>NFI Fuel Designs</td>
<td>144</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>145</td>
</tr>
<tr>
<td>• China National Nuclear Corporation (CNNC)</td>
<td>146</td>
</tr>
<tr>
<td>Corporate Structure and Manufacturing Facilities</td>
<td>146</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>147</td>
</tr>
<tr>
<td>Yibin Fabrication Plant</td>
<td>147</td>
</tr>
<tr>
<td>Baotou Fabrication Plant</td>
<td>148</td>
</tr>
<tr>
<td>Fuel Assembly Research &amp; Development</td>
<td>150</td>
</tr>
<tr>
<td>New Fabrication Facilities</td>
<td>150</td>
</tr>
<tr>
<td>Other Fabrication-Related Ventures</td>
<td>151</td>
</tr>
<tr>
<td>Current and Future Markets</td>
<td>152</td>
</tr>
<tr>
<td>Domestic Market</td>
<td>152</td>
</tr>
<tr>
<td>Foreign Markets</td>
<td>152</td>
</tr>
<tr>
<td>CNNC PWR Fuel Assemblies</td>
<td>153</td>
</tr>
<tr>
<td>Comprehensive Fuel Offerings</td>
<td>155</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>155</td>
</tr>
<tr>
<td>• Industrias Nucleares do Brasil (INB)</td>
<td>156</td>
</tr>
<tr>
<td>Ownership and Organization</td>
<td>156</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>157</td>
</tr>
<tr>
<td>INB Fuel Assembly Designs</td>
<td>158</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>159</td>
</tr>
<tr>
<td>• Nuclear Fuel Complex – India</td>
<td>160</td>
</tr>
<tr>
<td>Ownership and Organization</td>
<td>160</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>161</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>162</td>
</tr>
<tr>
<td>• Kazatomprom – Kazakhstan</td>
<td>163</td>
</tr>
<tr>
<td>Ownership and Organization</td>
<td>163</td>
</tr>
<tr>
<td>Fuel Fabrication Operations</td>
<td>164</td>
</tr>
<tr>
<td>Historical Background</td>
<td>164</td>
</tr>
<tr>
<td>Production Capacity</td>
<td>165</td>
</tr>
<tr>
<td>Fabrication Joint Ventures</td>
<td>166</td>
</tr>
<tr>
<td>• Framatome (formerly AREVA NP)</td>
<td>166</td>
</tr>
<tr>
<td>• China General Nuclear Power Corporation</td>
<td>166</td>
</tr>
<tr>
<td>• Russia</td>
<td>167</td>
</tr>
<tr>
<td>• Ukraine</td>
<td>167</td>
</tr>
<tr>
<td>Ownership Share in Westinghouse</td>
<td>168</td>
</tr>
<tr>
<td>Current and Future Markets</td>
<td>168</td>
</tr>
<tr>
<td>Russia</td>
<td>168</td>
</tr>
<tr>
<td>Western Fuel Fabricators</td>
<td>168</td>
</tr>
<tr>
<td>Japan</td>
<td>169</td>
</tr>
<tr>
<td>China</td>
<td>169</td>
</tr>
<tr>
<td>Possible Future Developments</td>
<td>170</td>
</tr>
</tbody>
</table>
5 – Supply and Demand Analysis

Forecast of Supply Capability
Worldwide Supply and Demand
Western European Supply and Demand
North America/Taiwan Supply and Demand
Asian Supply and Demand
Supply and Demand for VVER Reactors
Other Supply Considerations
Conclusions

6 – Global and Regional Market Analysis

BWR Fuel Markets
Western European BWR Fabrication Market
North American BWR Fabrication Market
Asian BWR Fabrication Market
Japan
Taiwan
PWR Fuel Markets
Western European PWR Fabrication Market
French PWR Fuel Market
PWR Fuel Market in the Balance of Western Europe
Siemens/KWU Units
Westinghouse Units
U.S. PWR Fabrication Market
Babcock & Wilcox Units
Combustion Engineering Units
Westinghouse Units
Asian PWR Fabrication Markets
Japan
Taiwan
South Korea
China
Eastern European PWR (VVER) Fabrication Market

7 – Nuclear Fuel Fabrication Prices

Fuel Fabrication Price Background
Fuel Fabrication Price Formation
History of Fuel Fabrication Prices
Initial Core and Reload Batch Prices
Current and Future Fabrication Prices
Utility Survey Responses
Current Fabrication Prices
Table of Contents

- Future Price Trends ................................................................. 226
  - UxC Fabrication Price Forecast .............................................. 228
    - Current Prices .............................................................. 230
    - Factors Affecting Future Prices ........................................ 230
    - Developments Retarding Price Increases ............................ 230
    - Developments Promoting Price Increases ........................... 230
    - Future Path of Fabrication Prices ..................................... 231
  - U.S. Fabrication Price Projections ....................................... 232
  - Prices Outside the U.S. ...................................................... 233
    - Western Europe .................................................................. 233
    - Japan ................................................................................ 234
    - China and South Korea ...................................................... 234
    - VVER Fuel ........................................................................ 235

8 – Non-LWR Fuel Fabrication Markets ........................................ 236

- Pressurized Heavy Water Reactor Fuel ....................................... 236
  - PHWR Overview .................................................................... 236
  - PHWR Fuel Overview ............................................................ 237
  - PHWR Fuel Fabricators .......................................................... 238
    - Cameco Fuel Manufacturing (Canada) .................................. 239
    - Description of Fabrication Facilities .................................... 239
    - Domestic and Foreign Markets Served .................................. 240
    - Fuel Assembly Designs and Services .................................... 240
    - BWXT Nuclear Energy Canada (Canada) ............................ 240
    - Description of Fabrication Facilities .................................... 241
    - Domestic and Foreign Markets Served .................................. 241
    - Fuel Assembly Designs and Services .................................... 241
    - KEPCO Nuclear Fuel (South Korea) ...................................... 242
    - Description of Fabrication Facilities .................................... 242
    - Domestic and Foreign Markets Served .................................. 242
    - Fuel Assembly Designs and Services .................................... 242
    - China National Nuclear Corporation (China) ....................... 242
    - Description of Fabrication Facilities .................................... 242
    - Domestic and Foreign Markets Served .................................. 243
    - Fuel Assembly Designs and Services .................................... 243
    - Fabrica de Combustible Nuclear (Romania) .......................... 243
    - Description of Fabrication Facilities .................................... 244
    - Domestic and Foreign Markets Served .................................. 244
    - Fuel Assembly Designs and Services .................................... 244
    - CONUAR S.A. (Argentina) ..................................................... 244
    - Description of Fabrication Facilities .................................... 245
    - Domestic and Foreign Markets Served .................................. 245
    - Fuel Assembly Designs and Services .................................... 245
    - Nuclear Fuel Complex (India) .............................................. 245
    - Description of Fabrication Facilities .................................... 246
    - Domestic and Foreign Markets Served .................................. 246
    - Fuel Assembly Designs and Services .................................... 246
    - Additional PHWR Fuel Related Companies ........................ 247
    - SNC-Lavalin (Canada) .......................................................... 247
    - Canadian Nuclear Laboratories (Canada) ............................ 247
    - TVEL Fuel Company (Russia) ............................................... 248
    - Kazatomprom (Kazakhstan) .................................................. 248
  - PHWR Fuel Supply and Demand Analysis ................................ 248
    - PHWR Fuel Market Analysis ................................................ 249
- Gas Cooled Reactor Fuel .............................................................. 250
  - GCR Overview .................................................................. 250
  - Springfields Fuels Ltd. (AGR) .................................................. 251
  - AGR Fuel Supply and Demand ............................................... 252

Light Water Cooled, Graphite Moderated Reactor Fuel ........................ 253

- LGR Overview .................................................................. 253
  - LGR Fuel Overview .............................................................. 253
  - LGR Fuel Supply and Demand Analysis .................................. 255

Small Modular and Advanced Reactor Fuel .................................. 257
List of Figures

Figure 1. 2018 Average U.S. Nuclear Generating Costs ($/MWh) .................................................. 16
Figure 2. U.S. Nuclear Generating Costs, 2002-2018 (in 2018 $/MWh) ........................................ 16
Figure 3. U.S. Nuclear Generating Cost Comparisons ($/MWh) ...................................................... 17
Figure 4. Responses to Question on Fabrication as Percent of Fuel Costs ................................... 19
Figure 5. Responses to Question on Fabrication Cost Direction in Next 5 Years ............................ 20
Figure 6. Responses to Question on Challenges to ATF Commercialization ...................................... 25
Figure 7. Responses to Question on Timing of ATF Commercialization ........................................ 26
Figure 8. Map of UxC Nuclear Regions ............................................................................................ 29
Figure 9. UxC Nuclear Generating Capacity Forecast, 2008-2035 .................................................. 31
Figure 10. UxC Base, High, and Low Case Nuclear Capacity Forecasts, 2008-2035 ....................... 33
Figure 11. Percentages of Different Operating Reactor Types .......................................................... 34
Figure 12. New Reactor Startups and Total MWe Added, 2019-2030 ............................................... 35
Figure 13. Percentages of New Reactor Types, 2019-2030 ............................................................... 36
Figure 14. Percentages of New Reactor Vendors, 2019-2030 ......................................................... 37
Figure 15. UxC Global LWR Fabrication Demand Forecast Cases, 2008-2035 ............................. 39
Figure 16. UxC Regional LWR Base Case Fabrication Demand Forecast, 2008-2035 .................... 40
Figure 17. UxC Fabrication Demand Forecast by Fuel Type, 2008-2035 ......................................... 41
Figure 18. Utility Responses to Question on “Services Under Contract” ........................................... 48
Figure 19. Framatome ATRIUM 10XM Fuel Assembly ................................................................. 60
Figure 20. Framatome AGORA H (left), HTP (center) and GAIA (right) Fuel Assemblies ........... 61
Figure 21. Framatome ATRIUM 11 Fuel Assembly ........................................................................ 62
Figure 22. GNF-A Fuel Loading Experience, 1999-2018 ................................................................. 71
Figure 23. GNF-A GNF2.02 Fuel Assembly ................................................................................... 71
Figure 24. GNF-A GNF3 Fuel Assembly ....................................................................................... 72
Figure 25. Westinghouse SVEA Optima 2, Optima 3, and Triton11 Fuel Assemblies .................... 87
Figure 26. Westinghouse RFA-2, NGF, CE16NGF, and AP1000 Fuel Assemblies ........................... 88
Figure 27. Westinghouse TVS-WR Fuel Assembly ........................................................................... 91
Figure 28. Distribution of TVEL’s 2018 Consolidated Revenue by Types of Products ................ 97
Figure 29. Geographic Distribution of TVEL’s Revenue from Nuclear Fuel Sales ........................ 97
Figure 30. MSZ’s VVER-1000 Fuel Fabrication Line ............................................................... 101
Figure 31. TVEL Fuel Assembly Offerings .................................................................................... 110
Figure 32. Evolution of TVEL’s VVER-440 Fuel Designs ................................................................. 111
Figure 33. TVEL VVER-440 TVS ARK Fuel Assembly (top) and RK-3 Assembly (bottom) .......... 112
Figure 34. Evolution of TVEL’s VVER-1000 Fuel Designs ............................................................... 113
Figure 35. TVEL TVSA-12 and TVS-4A Fuel Assemblies ............................................................... 115
Figure 36. TVEL TVS-KVADRA Fuel Assembly ............................................................................ 116
Figure 37. KNF PLUS7 (left) and ACE7 (right) Fuel Assemblies ...................................................... 123
Figure 38. ENUSA 17x17 MAEF Fuel Assembly ......................................................................... 133
Figure 39. MNF 17x17 Fuel Assembly ................................................................. 139
Figure 40. MNF US-APWR 17x17 Fuel Assembly ............................................. 140
Figure 41. NFI 9x9 BWR Fuel Assembly ........................................................... 144
Figure 42. NFI 17x17 PWR Fuel Assembly ....................................................... 145
Figure 43. First AP1000 Fuel Assemblies Produced in China ............................ 149
Figure 44. Chinese PWR Fuel Assemblies at CNNC’s Yibin Plant ..................... 153
Figure 45. CNNC’s CF3 Fuel Assembly ............................................................. 154
Figure 46. INB Fuel Assemblies at the Resende Plant ....................................... 158
Figure 47. Russia’s Dual-Component Nuclear Power System ............................. 187
Figure 48. Projected Worldwide LWR Supply, 2008-2035 ............................... 188
Figure 49. Worldwide LWR Fabrication Supply and Demand, 2008-2035 .......... 191
Figure 50. Western Europe LWR Fabrication Supply and Demand, 2008-2035 .... 193
Figure 51. North American/Taiwan LWR Fabrication Supply and Demand, 2008-2035 ................................................................. 195
Figure 52. Asian LWR Fabrication Supply and Demand, 2008-2035 .................. 196
Figure 53. VVER Fabrication Supply and Demand, 2008-2035 ......................... 198
Figure 54. Western European BWR Fabrication Market Shares ........................ 203
Figure 55. North American BWR Fabrication Market Shares .......................... 205
Figure 56. Western European PWR Fabrication Market Shares ........................ 209
Figure 57. U.S. PWR Fabrication Market Shares ............................................. 214
Figure 58. Total LWR Nuclear Fuel Price Breakdown ....................................... 221
Figure 59. Utility Responses to Question on “Future Fabrication Price Trends” .... 227
Figure 60. BWR Fabrication Price Forecast, 2019-2035 .................................... 233
Figure 61. PWR Fabrication Price Forecast, 2019-2035 ..................................... 233
Figure 62. PHWR Fuel Fabrication Manufacturing Process ............................. 237
Figure 63. PHWR Fuel Bundle ........................................................................ 237
Figure 64. PHWR Fuel Fabrication Supply and Demand, 2008-2035 ................. 249
Figure 65. AGR Fuel Bundle .......................................................................... 251
Figure 66. AGR Fuel Fabrication Supply and Demand, 2008-2035 ................... 252
Figure 67. RBMK-1000 Fuel Assembly ............................................................ 254
Figure 68. LGR Fuel Fabrication Supply and Demand, 2008-2035 .................... 256
Figure 69. HoltecSMR-160 Fuel Core Cartridge ............................................. 259
Figure 70. China HTR-PM TRISO Coated Particles and Fuel Spheres ............... 260
Figure 71. China’s Pilot HTR Fuel Production Line ............................................ 260
List of Tables

Table 1. Reactor Units & Nuclear Capacities Anticipated by Country by 2035 .......................... 31
Table 2. UxC Base, High, and Low Case Nuclear Reactor and Capacity Forecasts, 2018-2035 .......... 33
Table 3. Operating Reactor Types ......................................................................................... 34
Table 4. New Reactor Startups by Year, 2019-2030 .............................................................. 35
Table 5. New Reactor Types, 2019-2030 ............................................................................. 36
Table 6. New Reactor Vendors, 2019-2030 ......................................................................... 37
Table 7. UxC Global LWR Fabrication Demand Forecast Cases, 2019-2035 ......................... 39
Table 8. UxC Regional LWR Fabrication Demand Forecasts, 2019-2035 ............................. 40
Table 9. UxC Regional LWR Fabrication Demand Forecasts, 2019-2035 ............................. 41
Table 10. Survey Responses to Question on “State of the Market” ........................................ 43
Table 11. Worldwide LWR Fuel Fabrication Capacity in 2019 .................................................. 54
Table 12. TVEL Fuel Production Levels, 2014-2017 .............................................................. 98
Table 13. UMP Production, 2015-2017 ................................................................................. 165
Table 14. Base Case UxC Fabrication Supply Capacity Forecast, 2017-2030 .......................... 190
Table 15. Number of European BWR Plants Supplied ............................................................ 203
Table 16. Number of Western European PWR Plants Supplied* ........................................... 211
Table 17. Number of U.S. PWR Plants Supplied ................................................................. 214
Table 18. Historical Fabrication Prices, 2008-2018 ............................................................... 224
Table 19. Fabrication Price Projection, 2019-2035 ............................................................... 234
Table 20. Current Worldwide PHWR Fuel Fabrication Capacity ............................................ 238
Table 21. Comparative Data for Ten Leading SMR and Advanced Reactor Designs ................ 258
Table B-1. Mega-Vendor Fabrication Supplier Contacts ....................................................... 267
Table B-2. National and Regional Fuel Fabrication Supplier Contacts .................................... 268
Table C-1. Glossary of Terms .............................................................................................. 269
Introduction and Overview

UxC, LLC (UxC) is pleased to present the 2019 Fabrication Market Outlook (FMO) report, which is the 13th annual edition in this series. This year’s report builds upon the significant enhancements made in previous editions as part of our ongoing effort to improve information exchange and understanding in the all-important global nuclear fuel fabrication marketplace. This edition also continues numerous improvements made to the structure and format of the FMO report beginning with the 2017 edition.

The global nuclear industry is dealing with many headwinds these days, including the continuing aftereffects of the devastating Fukushima accident of 2011, the dramatic rise of competing energy forms (e.g., natural gas and renewables), as well as numerous negative policy initiatives in key countries around the world.

Beyond the well-known nuclear phase-out policies in places like Germany, Belgium, and Taiwan, there are also questions about the long-term operations of nuclear power plants in some of the dominant markets of the world. Concerns about premature reactor closures and new reactor cancelations are high in the U.S., which still maintains the world’s largest nuclear fleet. Recent changes to energy policies in key markets like France and South Korea are likely to reduce reliance on nuclear power. While France has already had such a policy in place for a while, the changing nature of South Korea’s nuclear policy has taken many in the industry by surprise.

On the positive side, China continues to move forward with its nuclear expansion albeit at a much slower pace than before Fukushima. There are also still many new reactors under construction around the world, including in the United Arab Emirates, India, Russia, and elsewhere. Meanwhile, with nine reactors approved for restart in Japan and several more in the pipeline, the story out of Japan is more positive than it has been in past years. Still, it remains unclear if more than half of Japan’s pre-Fukushima fleet will ever return to service. In the U.S., new state policies have helped avert several premature reactor shutdowns, but it remains to be seen how many more of the nine units slated for closure by 2025 can be saved.

Demand for nuclear fuel therefore has not seen any major increases over the past few years, and the forecasts for its growth in the coming decades have also diminished. Nevertheless, the world will clearly still need substantial amounts of nuclear fuel fabrication, and the industry will need to respond to the various competing trends on the demand side.

On the supply side, there have been some major events affecting the future outlooks for key fabrication vendors. The French conglomerate AREVA has been split into two companies, with the fuel fabrication division joining the reactor construction and services divisions in the new Framatome. So far, the effects of this restructuring on Framatome’s fuel fabrication business appear to be rather minimal, but some observers expect additional changes in the coming years.
Westinghouse’s purchase by Brookfield Business Partners is also continuing to have ripple effects. The new ownership under Brookfield has begun to show some larger results as executive level changes are underway and personnel cuts have also begun. However, many uncertainties still remain, and the changes on the fabrication business appear so far to be limited. Given that the fabrication division is one of the more profitable parts of Westinghouse’s business, one would expect that Brookfield will be loath to do anything that tarnishes its reputation or market standing.

Russian vendor TVEL, which is still the dominant VVER fuel supplier despite inroads by Westinghouse in Ukraine, has also been making major strides in its efforts to enter the western PWR reload market. However, following its first contract to supply a portion of the fuel for Vattenfall’s Ringhals 3 reactor in Sweden, TVEL has hit some roadblocks in its effort to team with Global Nuclear Fuel-Americas (GNF-A) to introduce PWR reload fuel in the U.S. as the U.S. government has refused to grant all the necessary technology transfer permits to the Russian company. As such, geopolitical concerns continue to hover over TVEL’s ability to expand its market reach.

These collective market developments, coupled with various other issues in the nuclear industry, in general, and the fuel fabrication industry, in particular, have suggested that there could be changes in worldwide fabrication markets. The interactions between buyers and sellers in the years ahead and our assessment of such changes are addressed throughout this FMO report, including in this year’s essay.

As with previous editions, the primary focus of this FMO report is fuel fabrication for large light water reactors (LWRs) – boiling water reactors (BWRs) and pressurized water reactors (PWRs) – since these comprise the great majority of the nuclear plants currently in operation around the world and those planned for the future. The Russian VVER reactors installed in Russia, Eastern Europe, and other countries are, in fact, PWRs.

There are also several pressurized heavy water reactors (PHWRs) operating in Canada and other nations, advanced gas-cooled reactors (AGR) in the United Kingdom, and several light water-cooled, graphite-moderated reactors (LGR) in Russia (RBMK and EGP reactors). However, these regions/reactors represent unique fuel fabrication markets, which are covered at the end of this report.

In the chapters that follow, we address many of the diverse commercial, institutional, economic, and technical aspects of nuclear fuel, fuel fabrication, and the international fuel fabrication market. The report is intended to serve a variety of purposes:

- For those with little knowledge of nuclear fuel fabrication and its markets, the FMO serves as a primer, providing a solid background in various aspects of the industry and an understanding of how its markets function.

- For those knowledgeable in the fundamentals of fabrication, the FMO offers analyses of a variety of its aspects based on several decades of participation in the fabrication industry.
• And, for those who are actively involved in the industry as buyers or sellers of nuclear fuel assemblies, the FMO supplies additional up-to-date insights to assist in the improvement of existing nuclear fuel programs and in the development of new fabrication-related initiatives.

What’s New in the 2019 Report?

In the 2019 FMO, we have updated all sections of the report and continued with the new organization and format of the report since the 2017 edition. This includes our new FMO Reference Document, which incorporates portions of the previous FMO reports that are considered reference materials and do not change from year to year very much.

The FMO presents market data and analysis consistent with the style of UxC’s other Market Outlook reports, and all the discussions and analyses have been updated to reflect the events of the past year. As part of the lead-up to this report, we have once again conducted a survey of international utility attitudes toward the fabrication market.

This year’s essay, titled “How Fabrication Fits Into the Bigger Fuel Picture,” examines how fabrication fits into the broader nuclear fuel cycle as it relates to utility fuel procurement and what recent and future trends might affect how fabrication will fit into the bigger fuel picture in the years to come. This discussion includes detailed reviews of the share of reactor operating costs associated with nuclear fuel procurement, and specifically fuel fabrication, and how these costs are likely to trend in the future.

Once again, we have classified the world’s fabricators into three categories: the Mega-Vendors, large international suppliers to multiple markets; Emerging International Suppliers, those companies who are poised to expand beyond their current regional markets to directly challenge the Mega-Vendors in their principal markets; and the smaller regional and national suppliers. Analysis of each vendor’s current situation and potential future developments in terms of market access and technical developments are presented in detail.

This year’s fuel fabrication demand projection is drawn from our proprietary UxC Requirements Model (URM), which, starting with UxC’s own internal forecasts for nuclear power capacities, calculates demand on a reactor-by-reactor, cycle-by-cycle basis. We continue to refine and improve our reactor forecasts and the URM and believe the current version of the Model produces more accurate forecasts than in prior years. UxC’s nuclear growth forecasts are updated quarterly, and the fabrication demand projections used in this report reflect our very latest analyses in this regard. In this 2019 edition, we again present extended supply and demand as well as price forecasts through 2035.

The focus of the report are analyses of the current and future markets for fuel for LWRs, i.e., BWRs and PWRs; however, we also include an updated and expanded
discussion of the fabrication markets for non-LWR fuel (e.g., PHWRs, AGRs, and LGRs). Special efforts have been made to enhance our analysis of the PHWR fuel fabrication market, which represents about 11% of the world’s reactors today. In addition, we have once again included a brief review of the potential fuel fabrication market for small modular reactors (SMRs) and other advanced reactors, although the future of SMRs and other advanced reactor designs remains in flux at this time.

Finally, as part of our continuing efforts to improve and enhance the analysis of the fuel fabrication markets, UxC made efforts to engage with global fuel fabricators, as well as their customers, to obtain the most accurate and up-to-date information possible. For this year’s Utility Fabrication Market Survey, we received many excellent responses from utilities around the world.

- **FMO Reference Document**

As a major change to our previous FMO reports, we have also decided to split the FMO report into two documents. The first is this main FMO report, which includes all the chapters described in the following Structure of Report section. Second, in order to make the FMO more user-friendly, and to reduce the total volume of the main report, we have extracted sections of the previous FMO that have remained relatively constant over the years and put them into a separate FMO Reference Document. This reference document is available to all FMO subscribers and can be accessed as a PDF file downloadable from the UxC Client Site (note that subscriber login credentials are required).¹ The FMO Reference Document includes the following sections:

- Nuclear Fuel Fabrication Market Primer
- History of the Nuclear Fuel Fabrication Industry
- Utility Procurement Approaches and Contracting Issues
- Typical Fuel Fabrication Service Contracts
- Fuel Assembly Design, Manufacture & Performance

**Structure of Report**

This year’s edition of the FMO continues our efforts to create a user-friendly text with each chapter containing clear and distinct information. The reader is encouraged to begin at Chapter 1, as there is intended to be a continuous and logical flow to the report; however, each individual chapter provides unique topical coverage that can also be considered independently from the rest of the report’s contents. The report is structured as follows:

¹ Access to the FMO subscriber website is at: https://www.uxc.com/c/MktRptEssays.aspx?rpt=fmo
This year’s in-depth topical essay in Chapter 1 – Essay: How Fabrication Fits Into the Bigger Fuel Picture examines the role that fuel fabrication plays in terms of utility operating and fuel cycle costs and also what recent and near-term new industry trends will affect the way that fuel fabrication fits into utility fuel cycle and procurement considerations.

Chapter 2 – Reactor Developments and Demand Outlook begins our review of the fabrication market fundamentals with a look at current and future demand. This chapter presents UxC forecasts for nuclear power growth through 2035 from our Nuclear Power Outlook (NPO) and the resulting fabrication demand projection through 2035 using our UxC Requirements Model (URM).

Chapter 3 – Results from UxC Utility Fabrication Market Survey presents the results of our latest utility market survey and analyzes the latest trends in utility views on the fabrication market.

The supply side of the equation is addressed in Chapter 4 – The World’s Nuclear Fuel Fabricators. This chapter includes in-depth profiles of each of the world’s LWR fuel suppliers, their production facilities, their products, the markets they serve, and additional items of interest.

Chapter 5 – Supply and Demand Analysis combines all of the preceding discussions with a comparison of supply and demand for LWR fuel through 2035 on a global level as well as in each of the principal geographic market segments.

Since the market for fabricated LWR fuel is segmented both geographically and technically, each of these individual market segments is discussed and analyzed in Chapter 6 – Global and Regional Market Analysis.

Chapter 7 – Nuclear Fuel Fabrication Prices discusses the factors affecting current and future LWR fuel prices and presents UxC’s latest projections for both PWR and BWR fuel fabrication prices in different regional markets through 2035.

Finally, in Chapter 8 – Non-LWR Fuel Fabrication Markets, we present a discussion of the unique fuel fabrication markets for pressurized heavy water reactors (PHWRs), gas cooled reactors (GCRs), and light water cooled, graphite-moderated reactors (LGRs). Small Modular Reactor (SMR) and advanced reactor fuel developments are also addressed at the end of this chapter.

The report also contains a series of appendices and a glossary, which provide background information and other useful items on the fabrication market. The following are found at the end of this report:

Appendix A – UxC 2019 Fuel Fabrication Market Survey Sample

Appendix B – Fuel Fabricator Contact Information

Glossary