Global Nuclear Fuel Inventories
NOTICE

UxC, LLC ("UxC") shall have title to, ownership of, and all proprietary rights in this Report. Under United States federal copyright law (17 USC 101 et seq.) it is illegal to reproduce this Report by any means without written permission from UxC.

The information contained in this Report is obtained from sources that UxC believes to be reliable. UxC makes no warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this Report and UxC, to the maximum extent permitted by law, assumes no liability for the use or effects of any of the information or data contained in this Report.

It is UxC's strict policy not to endorse, promote, or recommend any particular securities, currencies, or other financial products or instruments. Nothing contained in this Report is intended to constitute investment, legal, tax, accounting or other professional advice and the reader should not rely on the information provided in this Report for making financial decisions.

The Ux U3O8 Price® and other Ux Price indicators are developed by UxC and are proprietary and exclusive intellectual property of UxC. These price indicators are provided to UxC’s customers through the Ux Weekly® publication and are made available on UxC’s public website solely at UxC’s discretion. They may not be reproduced or otherwise used without UxC’s express permission.

UxC®, Ux Weekly®, Ux U3O8 Price®, UxC BAP®, U-PRICE®, and SWU-PRICE® are trademarks of UxC, LLC.
# Table of Contents

**Introduction & Overview**
- Purpose of Report .................................................. 7
- What’s New in the 2020 Edition? .................................. 8
- Structure of Report .................................................. 8

**1 – Inventories in Context** ........................................ 10
- Fundamentals of Inventories ..................................... 10
  - The Nuclear Fuel Cycle ......................................... 10
  - Forms of Inventories ............................................ 12
  - Inventory Holders ............................................... 13
- Utility Inventories ................................................. 14
  - Types of Inventories ............................................ 14
    - Pipeline ....................................................... 14
    - Strategic ..................................................... 14
    - Other ......................................................... 14
  - Brief History of Regional Utility Inventories ............ 15
    - United States ............................................... 15
    - Europe ....................................................... 16
    - Japan .......................................................... 17
    - China, Russia, South Korea, and India ................... 17
- Supplier Inventories ............................................. 18
- Government Inventories ........................................ 20
  - United States .................................................. 20
  - Russia ........................................................... 20
- Inventories and the Market ..................................... 21
- Other Inventory Developments ................................ 25
  - Financial Inventories ......................................... 25
  - Nuclear Fuel Banks ............................................ 26
- Inventories Created by Excess Supply Capacities ....... 26

**2 – Assessing Current Inventories: Utilities** .............. 28
- United States ..................................................... 28
  - Current Inventory Levels ..................................... 28
    - Analysis of Recent EIA Data ............................... 30
  - Individual Utility Data ....................................... 30
  - Inventory Changes Since 2018 Report ..................... 32
  - Location of Inventories ...................................... 32
  - Forward Coverage ............................................ 32
  - Impact of Reactor Shutdowns ................................. 33
  - Future Outlook ............................................... 34
- European Union .................................................... 36
  - Current Inventory Levels ..................................... 36
  - Individual EU Country and Utility Profiles ............... 37
    - France – EDF ................................................... 38
    - Germany – RWE, Preussen Elektra, & EnBW ............. 38
    - United Kingdom – EDF Energy ............................. 38
    - Sweden – Vattenfall & Uniper ............................. 39
    - Spain – ENUSA (Endesa, Iberdrola, & Naturgy) ....... 39
    - Belgium – Synatom (Electrabel) ........................... 39
    - Finland – TVO & Fortum ..................................... 39
    - Netherlands – EPZ ........................................... 40
    - Slovakia – Slovenské Elektrárne ......................... 40
    - Bulgaria – Kozloduy ......................................... 40
    - Czech Republic – ČEZ ....................................... 40
    - Hungary – MVM Paks ........................................ 40
    - Romania – SNN ............................................... 41
  - Inventory Changes Since 2018 Report ..................... 41
  - Location of Inventories ...................................... 41
  - Forward Coverage ............................................ 41
• Impact of Reactor Shutdowns .......................................................... 42
• Future Outlook ............................................................................. 43

Japan ................................................................................................. 46
• Current Inventory Levels ............................................................. 46
• Inventory Changes Since 2018 Report ........................................ 48
• Location of Inventories ................................................................. 49
• Forward Coverage ....................................................................... 49
  Impact of Future Fuel Deliveries .................................................. 52
• Future Outlook ............................................................................. 53
  Future of Japan’s Closed Nuclear Fuel Cycle ............................... 55

China ................................................................................................. 56
• Current Inventory Levels ............................................................. 56
  Inventory Forms ........................................................................... 58
  Total Inventory Quantities ............................................................ 58
• Inventory Changes Since 2018 Report ........................................ 59
• Location of Inventories ................................................................. 59
• Forward Coverage ....................................................................... 60
• Future Outlook ............................................................................. 61
  Future Uranium Imports ............................................................... 62
  Future of Inventories ................................................................. 64

Other Utilities .................................................................................. 65
• South Korea – Korea Hydro and Nuclear Power (KHNP).............. 65
• Russia – Rosenergoatom ............................................................... 66
• Canada – Bruce Power, OPG, and NB Power ............................... 66
• Ukraine – Energoatom ................................................................. 67
• India – Nuclear Power Corporation of India Ltd. (NPCIL) ............ 68
• Others ........................................................................................... 69
  Taiwan – Tainpower ................................................................. 69
  Switzerland – Axpo & KKG ......................................................... 69
  Mexico – CFE ............................................................................. 69
  Brazil – Eletronuclear & INB ......................................................... 70
  Argentina – NA-SA & Dioxitek .................................................... 70
  South Africa – Eskom ................................................................. 70
  UAE – ENEC ............................................................................. 70
  Pakistan – PAEC ......................................................................... 71
  Iran – Bushehr NPP ................................................................. 71
  Belarus – Belenergo ................................................................. 71
  Armenia – Metzamor NPP ......................................................... 72

• Inventory Changes Since 2018 Report ........................................ 72
• Summary ..................................................................................... 73

3 – Assessing Current Inventories: Suppliers & Intermediaries .......... 74
Suppliers .......................................................................................... 74
• U.S. Supplier Data ....................................................................... 74
• Orano ........................................................................................... 76
• Cameco ...................................................................................... 76
• URENCO ................................................................................... 77
• Russian Suppliers: ARMZ, Uranium One, TENEX, and TVEL .......... 78
  ARMZ .................................................................................... 78
  Uranium One ............................................................................ 78
  TENEX ................................................................................... 78
  TVEL ..................................................................................... 79
• Kazatomprom ........................................................................... 80
• Navig Mining and Metallurgical Combine .................................. 81
• Fabricators – Framatome, Westinghouse, GNF, KEPCO, etc. ........ 81
• Other Suppliers .......................................................................... 82

Traders and Financials ..................................................................... 83
• Brokers ....................................................................................... 83
• Traders ....................................................................................... 83
• Banks ......................................................................................... 84
• Hedge Funds .............................................................................. 85
4 – Assessing Current Inventories: Governments & Others .................................................. 88

United States Government .................................................................................................. 88
- Highly Enriched Uranium ................................................................................................. 90
  HEU Downblending Offering for Tritium (DBOT) .............................................................. 90
- U.S. and Russian-Origin Natural UF₆ .................................................................................. 91
- Off-Spec UF₆ and Non-UF₆ ............................................................................................... 92
- Depleted Uranium as UF₆ .................................................................................................. 93
  Depleted Uranium – 2012 Program ................................................................................... 93
  Depleted Uranium – Global Laser Enrichment (GLE) ..................................................... 93
- Other U.S. Inventory Categories ....................................................................................... 94
  Plutonium .......................................................................................................................... 94
  MOX Backup Inventory Program .................................................................................... 95
- Uranium Reserve ............................................................................................................... 96
- Disposition of Excess U.S. Government Inventories ........................................................ 98
  UxC Forecasts for U.S. Government Inventory Disposition .......................................... 99
- Summary .......................................................................................................................... 99

Russian Government ......................................................................................................... 101
- Reprocessed Uranium ...................................................................................................... 101
- Slightly Irradiated Uranium .............................................................................................. 102
- Highly Enriched Uranium ............................................................................................... 103
  HEU Feed Monitored Inventory ....................................................................................... 104
- Plutonium .......................................................................................................................... 104
- Depleted Uranium ............................................................................................................ 106
- Summary .......................................................................................................................... 107

- Russia’s Fuel Bank ........................................................................................................... 109
- American Assured Fuel Supply ....................................................................................... 110
  Uranium Reserve ............................................................................................................. 110
- IAEA Fuel Bank ............................................................................................................... 111
- Summary .......................................................................................................................... 111

Other Inventories ............................................................................................................... 112
- Excess Military and Civilian Separated Plutonium ......................................................... 112
- Reprocessed Uranium ...................................................................................................... 114
  France ............................................................................................................................... 114
  Japan ................................................................................................................................. 114
  UK ..................................................................................................................................... 115
  Others ............................................................................................................................... 115
- Iran .................................................................................................................................. 116

5 – Market Analysis and Global Forecasts ........................................................................ 117

Total Global Inventories .................................................................................................... 117
- Changes in Totals Since 2018 Report ............................................................................... 118

Factors Contributing to Current Inventory Conditions .................................................. 120
- Legacy of a Thwarted Nuclear Renaissance ................................................................... 120
- A Gradual Shift in Market Mentality ............................................................................... 121
- Reduction Cutbacks Leading to Inventory Work-Off ...................................................... 121

Pipeline vs. Strategic vs. Excess Inventories ................................................................. 122
- Utilities .............................................................................................................................. 122
  Regional Utility Analysis ................................................................................................. 123
- Suppliers .............................................................................................................................. 123
- Traders and Financials ...................................................................................................... 124
- Governments .................................................................................................................... 124
- Summary .......................................................................................................................... 124

Inventory Mobility ............................................................................................................. 125
Table of Contents

- Forms of Inventories ........................................................................................................... 125
- Locations of Inventories .................................................................................................. 126
- Holders of Inventories ...................................................................................................... 127
- Other Considerations ........................................................................................................ 127
- Mobility of Japanese Inventories .................................................................................... 127

Inventories in the Era of COVID-19 .................................................................................... 129
- Potential for Additional Inventory Buying ....................................................................... 129
- Potential for Additional Inventory Disposition .................................................................. 129

Inventory Carrying Costs .................................................................................................... 130

National Security Policies Influencing Inventory Levels ................................................ 131

Uranium Inventory Forecasts and Market Analysis ............................................................. 132
- Inventory Growth vs. Disposition ...................................................................................... 132
  Inventory Growth .............................................................................................................. 132
  Inventory Disposition ...................................................................................................... 132
- UxO Forecasts ..................................................................................................................... 133
  Base Case .......................................................................................................................... 133
    • Utility Forecast ............................................................................................................. 133
    • Global Forecast .......................................................................................................... 134
  High Case .......................................................................................................................... 136
  Low Case ........................................................................................................................... 137
- Market Analysis .................................................................................................................. 138
  China’s Outsize Global Role ............................................................................................. 139
- Inventories Driving Uranium Spot and Mid-Term Contracting ....................................... 140

Conversion Inventory Forecasts and Market Analysis ......................................................... 141
- UxO Forecasts ..................................................................................................................... 141
  Base Case .......................................................................................................................... 141
  High and Low Cases ......................................................................................................... 142
- Market Analysis .................................................................................................................. 143
  Disconnected Conversion Prices: Spot vs. Long-Term .................................................... 144

Enrichment Inventory Forecasts and Market Analysis ...................................................... 145
- Inventory Forecasts ............................................................................................................ 145
  Base Case .......................................................................................................................... 145
  High and Low Cases ......................................................................................................... 146
- Market Analysis .................................................................................................................. 147
  Enrichment and Uranium Price Divergence .................................................................... 147

Government Inventory Disposition Forecast ..................................................................... 149
- U.S. Government Dispositions ......................................................................................... 149
- Russian Government Dispositions ................................................................................. 150
- Uranium Disposition Forecasts ........................................................................................ 150
  Base Case .......................................................................................................................... 150
  High and Low Cases ......................................................................................................... 151
  Conversion Market Impacts ............................................................................................... 152
- Enrichment Disposition Forecasts .................................................................................... 152
- Market Analysis .................................................................................................................. 154

Long-Term Market Outlook ................................................................................................. 155

6 – Summary and Conclusions ........................................................................................... 157
List of Figures

Figure 1. The Nuclear Fuel Cycle ................................................................. 10
Figure 2. U.S. Inventory Holdings, 1987-2019 ............................................. 15
Figure 3. EU Utility Inventory Holdings, 2005-2019 ...................................... 16
Figure 4. U.S. Supplier/Broker/Trader Inventory Holdings, 1987-2019 ............. 19
Figure 5. World Uranium Production, Requirements, and Prices, 1948-2020 ........... 21
Figure 6. UxU3O8 Spot Price, 2000-2020 ....................................................... 23
Figure 7. Spot Purchases of Uranium, 1990-2020 ........................................ 23
Figure 8. Historical Buildup and Drawdown of Uranium Inventories, 1948-2020 ....... 24
Figure 9. SWU vs. Uranium Feed Requirements at Various Tails Assays ............. 26
Figure 10. U.S. Utility Inventories by Form, 1983-2019 .................................... 29
Figure 11. EU Utility Inventories, 2005-2019 ............................................... 36
Figure 12. Japanese Utility Nuclear Fuel Holdings, 2010-2019 ......................... 48
Figure 13. UxC Forecast Scenarios for Japanese Reactor Restarts, 2015-2027 ........... 50
Figure 14. China Uranium Supply/Demand Balance, 2000-2019 ....................... 57
Figure 15. China Nuclear Fuel Imports by Form, 2000-2019 ............................ 58
Figure 16. China Uranium Imports by Country of Origin, 2001-2017 ................. 62
Figure 17. U.S. Supplier Inventories, 1987-2019 .......................................... 74
Figure 18. U.S. Supplier vs. Broker/Trader Inventories, 2004-2019 ................... 75
Figure 19. Slightly Irradiated Uranium (SIU) and Depleted SIU as Byproduct of Pu Production .............................................................. 102
Figure 20. Global Plutonium Inventories, 1945-2015 ..................................... 113
Figure 21. UxC Pre-Fukushima vs. Current Nuclear Power Forecasts, 2008-2035 ....... 120
Figure 22. Major Market Government Interest Rates, 1963-2019 ....................... 130
Figure 23. UxC Base Case Forecast for Global Uranium Inventories, 2008-2035 ...... 135
Figure 24. UxC High Case Forecast for Global Uranium Inventories, 2008-2035 .... 136
Figure 25. UxC Low Case Forecast for Global Uranium Inventories, 2008-2035 ...... 137
Figure 26. UxC Base Case Utility Inventory Forecast without China, 2008-2035 ....... 139
Figure 27. Uranium Spot and Mid-Term Contracting Volumes, 2008-2020 ............ 140
Figure 28. UxC Base Case Forecast for Global Conversion Inventories, 2008-2035 .... 142
Figure 29. Ux Conversion Prices – Spot and Long-Term, 1995-2020 ................... 144
Figure 30. UxC Base Case Forecast for Global Enrichment Inventories, 2008-2035 .... 146
Figure 31. Comparison of Ux SWU and U3O8 Prices, 2004-2020 ....................... 148
Figure 32. UxC Base Case Forecast for Government Inventories in U3O8, 2008-2035 .... 151
Figure 33. UxC Forecast Cases for Government Inventories in U3O8, 2008-2035 ....... 152
Figure 34. UxC Base Case Forecast for Government Inventories in SWU, 2008-2035 .... 153
List of Tables

Table 1. Examples of Recent Nuclear Supply Chain Production Events ........................................ 18
Table 2. Uranium Supply vs. Consumption, 2014-2019 ................................................................. 27
Table 3. U.S. Utility Inventories in 2019 ...................................................................................... 29
Table 4. Recent Changes in U.S. Utility Inventories, 2016-2019 .................................................. 30
Table 5. U.S. Utility Nuclear Fuel Holdings Financial Values, 2010-2019 ................................. 31
Table 7. EU Utility Inventories in 2019 ......................................................................................... 37
Table 8. EDF Nuclear Fuel Inventory Financial Values, 2010-2019 ............................................ 38
Table 9. EDF Energy Nuclear Fuel Inventory Financial Values, 2012-2018 ............................... 38
Table 10. Vattenfall Nuclear Fuel Inventory Financial Values, 2010-2019 ............................... 39
Table 11. TVO & Fortum Nuclear Fuel Inventory Financial Values, 2010-2019 ......................... 40
Table 12. EU Utility Forward Coverage Levels, 2008-2019 ......................................................... 41
Table 13. EU Reactor Closures, 2011-2020 .................................................................................. 42
Table 14. Anticipated EU Reactor Closures by 2025 .................................................................. 42
Table 15. Japanese Utility Inventory Estimates as of End of 2019 .............................................. 47
Table 16. Japanese Utility Inventories in 2019... ....................................................................... 48
Table 17. UxC Base Case Forecast for Japanese Reactors Operating by Utility, 2020-2035 ......... 50
Table 18. UxC Base Case Uranium Requirements Forecast for Japanese Utilities, 2020-2035 .... 51
Table 19. Japanese Utility Inventories vs. Requirements, 2020-2035 ......................................... 51
Table 20. Chinese Uranium Inventory Growth, 2004-2019 .......................................................... 57
Table 21. Chinese Utility Inventories in 2019 ............................................................................. 58
Table 22. UxC Forecast Scenarios for China, 2020-2035 ............................................................ 61
Table 23. Total China Uranium Imports by Country, 2001-2017 ................................................. 63
Table 24. Nuclear Fuel Inventory Estimates for Other Country Utilities as of 2020 ................. 73
Table 25. Cameco Inventory Holdings, 2016-2020 .................................................................. 76
Table 26. TVEL Inventory Holdings ......................................................................................... 79
Table 27. Supplier & Investor Inventories in 2020 ..................................................................... 87
Table 28. Total Volumes of U.S. Government Inventories as of End of 2019 ......................... 89
Table 29. UxC Base Case Forecast for U.S. Government Inventory Disposition, 2018-2035 .... 99
Table 30. Total Volumes of Russian Government Inventories as of End of 2019 ...................... 108
Table 31. Multilateral Security of Supply Mechanisms (Fuel Banks) ......................................... 111
Table 32. Civilian Plutonium Inventories .................................................................................... 112
Table 33. Total Global Nuclear Fuel Inventories as of 2020 ..................................................... 117
Table 34. Volumetric Changes to Total Global Nuclear Fuel Inventories since 2018 Report .... 119
Table 35. Percentage Changes to Total Global Nuclear Fuel Inventories since 2018 Report .... 119
Table 36. Estimate for Global Desired Utility Inventories .......................................................... 122
Table 37. Estimate for Regional Desired Utility Inventories ...................................................... 123
Table 38. UxC Base Case Forecast for Global Utility Inventories, 2018-2035 ......................... 134
Table 39. UxC Base Case Forecast for Global Uranium Inventories, 2018-2035 .................. 135
Table 40. UxC High Case Forecast for Global Uranium Inventories, 2018-2035 ..................... 136
Table 41. UxC Low Case Forecast for Global Uranium Inventories, 2018-2035 .................... 137
Table 42. UxC Base Case Forecast for Global Conversion Inventories, 2018-2035 ................. 142
Table 43. UxC Base Case Forecast for Global SWU Inventories, 2018-2035 ......................... 146
Table 44. UxC Base Case Forecast for Government Inventories in U_3O_8, 2018-2035 ............ 151
Table 45. UxC Forecast Cases for Government Inventories in U_3O_8, 2018-2035 .................... 152
Table 46. UxC Base Case Forecast for Government Inventories in SWU, 2018-2035 .............. 153
Introduction & Overview

UxC, LLC (UxC) is pleased to present our third edition of this special report on the topic of Global Nuclear Fuel Inventories. The inaugural edition of this report, published in December 2015, represented a first-of-a-kind effort by UxC to assemble and categorize all the available information related to nuclear fuel inventories around the world and provide insights and analysis on this important topic. A second edition, published in February 2018, built and improved upon the first edition, introducing notable changes to our analysis. This new June 2020 edition further expands the work in the previous reports by providing updated data on global nuclear fuel inventories along with enhanced analysis of the latest trends related to these inventories.

There is perhaps no bigger issue to emerge in the nuclear fuel markets over the last decade than the growing influence of inventories, especially following the drop in global demand after the March 2011 Fukushima accident. This updated 2020 report presents UxC’s detailed research and analysis on the topic of inventories to expand market understanding of this important issue and to provide expert forecasts regarding the future role that inventories will play in all the nuclear fuel market sectors.

Purpose of Report

There are many key questions surrounding the current state and future outlook nuclear fuel inventories. This report’s primary objective is to provide comprehensive analyses and forecasts and respond to these and related questions. Some of the most critical questions that this report attempts to answer include the following:

- What are the total current inventory levels in each key region/country?
- Who holds these inventories and in what form?
- Where could we see future increases or reductions in inventories?
- How do current inventory levels compare to previous estimates?
- How much of these inventories is pipeline versus strategic?
- How much of these inventories can be considered “excess” or “unobligated?”
- What is the mobility of excess inventories and what factors affect how unwanted holdings may be sold or disposed of?
- What is the likely future course of disposition for government-held inventories?
- What is the potential future impact of these inventories on each of the three nuclear fuel component markets (uranium, conversion, and enrichment)?
- What critical market conditions will influence the state of inventories over the long-term?
What’s New in the 2020 Edition?

With this third edition of the GNFI report, we have made several important enhancements and added new items to address the current market conditions, including:

- Updated data and analysis of all utility, supplier, trader/financial, and government inventory levels
- Provided new insights into the level of utility forward coverage rates and how these may evolve in the coming years
- Included detailed reviews of nuclear fuel inventory-related financial data of individual utilities from the past ten years
- Added individual profiles of EU nuclear power countries given unique differences among each in terms of inventory policies and utility approaches
- Revised forecasts for future inventory buying and disposition and how these look for each of the uranium, conversion, and enrichment sectors
- Updated our analysis of U.S. and Russian government stockpiles and their likely future usage
- Added a new section on international fuel banks to highlight the unique role that these sequestered pockets of material play in the global nuclear industry
- Increased analysis of the market impacts of inventories and key considerations for all market players for all three fuel cycle component sectors
- Added analysis on the role of inventories in the face of supply risks, including recent supply shocks due to the 2020 COVID-19 pandemic

Structure of Report

In addition to this Introduction & Overview, the report includes the following four chapters:

Chapter 1 – Inventories in Context introduces the key factors that frame the topic of nuclear fuel inventories, including historical perspectives and important market considerations. The chapter also briefly covers the main types of inventories and their holders as well as some of the primary reasons for the current excess inventory supply situation.

The next three chapters include the bulk of the research information compiled for this report. Detailed examinations of each of the inventory holding groups are presented, including current inventory levels, forward coverage, and future needs for inventories, as well as potential future disposition trends. These chapters proceed as follows:

Chapter 2 – Assessing Current Inventories: Utilities, which includes detailed inventory discussions of all major countries and regions with nuclear power plants.
Chapter 3 – Assessing Current Inventories: Suppliers & Intermediaries, which focuses on inventories held by major nuclear fuel suppliers and other market participants, such as from the trading and financial communities.

Chapter 4 – Assessing Current Inventories: Governments & Others, which analyzes the state of U.S. and Russian government inventories, along with international fuel banks and other unique holdings, such as civilian plutonium stockpiles.

Chapter 5 – Market Analysis and Global Forecasts introduces UxC’s market impact analysis and forecasts for future inventory growth and disposition and how these will affect the three nuclear fuel commodity markets – uranium, conversion, and enrichment. The chapter includes a detailed summary of the current estimates for the world’s nuclear fuel inventories along with a comparison with our previous estimates presented in 2018 to provide a view of how global inventories have shifted over the past two years. Multiple scenarios for future inventory growth/disposition are also examined along with relevant market implications. Additional detailed analyses of factors influencing the current and future trends in inventories as well as the overall market impacts of inventories are also provided. These include analyses on the level of current “excess” inventories and their mobility as well as possible implications of the COVID-19 supply shocks on inventory holdings.

Chapter 6 – Summary and Conclusions summarizes the key points of the report and offers some final thoughts on the nature of inventories and how they fit into the nuclear fuel markets.