UXC Special Report
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Nuclear Industry Value Chain

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Introduction & Overview

UxC, LLC (UxC) is pleased to present this seventh edition of our special report on the ***Nuclear Industry Value Chain*** (NIVC) to provide an overview of each of the market sectors within the nuclear industry, including the front-end fuel markets, the overall nuclear reactor sector, as well as the back-end of the fuel cycle. This updated December 2018 edition includes detailed data and analysis of every aspect of the global nuclear markets with balanced perspectives on commercial and technical issues affecting all parts of the value chain.

Although the nuclear industry continues to be impacted by the fallout from the Fukushima accident in March 2011 as well as other shifts in the broader energy markets, such as the shale gas boom in the U.S. and increasing levels of renewables, there are still many reasons for a continued expansion of global nuclear power, especially in key countries like China, India, and parts of the Middle East. The key arguments for nuclear expansion include rapid growth in electricity demand, increased concerns over greenhouse gas emissions, and a desire by nations to diversify their energy portfolios in the name of "energy security." Now is the time to assess the prospects and future course of each of the market sectors in this evolving, global industry. Each market sector has its own unique characteristics, and this report provides the reader with all the necessary tools to start the process of understanding the opportunities and potential pitfalls within each sector.

Purpose of Report

This report's primary objective is to provide comprehensive analyses of each of the sectors that make up the global nuclear industry. The goal is to examine the current status and future prospects (through 2035) for each sector comprising the entire "nuclear industry value chain," so as to support future decisions by investors, potential new entrants, as well as current participants in the global nuclear markets.

Combining UxC's decades of experience and knowledge of the nuclear industry, this report provides detailed data and information along with practical analysis for anyone considering entry or expansion in the dynamic nuclear marketplace. Whatever your position in the nuclear power arena, it is vital to seriously explore the future of the nuclear industry and the broader trends that will impact it going forward.

While the report attempts to follow a standard format in describing each market sector, it is important to understand that each sector is unique and requires special attention to the characteristics that define it. As this is an overview report, it can obviously not do every market sector justice in describing each detail. Nonetheless, our aim is to provide a thorough analysis and context to allow for a broader understanding of the current and future prospects of each market sector.

It should also be noted that although this report is intended as an introduction to the global nuclear markets, it assumes a reasonable level of knowledge of nuclear-related

technologies as well as familiarity with the history of the nuclear industry and developments in the nuclear fuel cycle since the inception of the peaceful use of the atom in the 1950s. If further explanation of anything in this report or related topics is required, UxC's team of nuclear market and technical experts is available for specialized consultations. In addition, UxC publishes many other detailed reports on the various nuclear market sectors that are available for purchase.

Key Questions in the Nuclear Markets Today

The following list presents some of the major issues and concerns that are present in the nuclear energy markets in late 2018. This NIVC report attempts to provide information and analysis to help inform and respond to many of these critical questions.

- Are the nuclear phase-out policies in various countries permanent, or will they realize that turning their back on nuclear may not be in their best interest?
- Can state and federal policies in the U.S. be enacted to keep additional reactors from shutting down?
- Is France's nuclear target to reduce reliance on nuclear power to 50% (down from 75%) achievable? And if so, what time frame will reactor shutdowns occur?
- When and how many of Japan's reactors restart? Can Japan build new reactors in the future to maintain its nuclear capacity level?
- What is causing the slowdown in China's nuclear program and is this a temporary issue or a sign of more trouble in the future?
- Will geopolitics and economic factors impact Russia's domestic reactor program and efforts to export numerous nuclear power plants?
- How can the UK manage the Brexit fallout for its nuclear industry and related international trade?
- Which potential newcomer countries can achieve real progress in developing nuclear power programs?
- Can real progress be made on small modular reactors (SMR) and other advanced reactor designs to make them viable for future deployment?
- What are the competitive positions of the various reactor vendors? Which companies have the upper hand in the current global marketplace?
- Have the uranium, conversion, and enrichment markets hit their bottoms and are the recent price upticks a sign of further upward moves?
- Will the current high level of nuclear fuel inventories lead to rapid dispositions on the part of some utilities?
- Can countries finally make progress with spent nuclear fuel disposal plans?
- Is the decommissioning market primed for fast growth due to all the reactor closures since Fukushima?

What's New in the 2018 Report?

Given that this is the seventh edition of the NIVC report, UxC has once again endeavored to make significant improvements over past editions in terms of the content, presentation of the information, and overall analysis in this global review of the nuclear marketplace. Highlights of the latest improvements in this new report include:

- The report begins with a broad introductory section on "Nuclear Power in the World Today," which has been updated to the current market situation as of late 2018. This section provides the overarching context for the global nuclear industry to help inform the follow-on analyses of the specific nuclear market sectors.
- Forecasts for nuclear power as well as supply/demand and prices for each market sector have been updated and extended out to 2035 based on UxC's complete review of the world on a country-by-country basis. The forecasts in this report reflect those published in other UxC reports as of the fourth quarter (Q4) of 2018.
- Current and future market trends are provided for each industry sector with a view to describing how the new realities in today's market will lead to significant changes in each market sector over the coming two decades.
- Each of the four front-end fuel chapters includes detailed discussions of how recent events (e.g., reduced demand, increased enricher underfeeding, cutbacks in production at mines and fuel cycle facilities, high inventory levels, shifts in contracting activity, etc.) are creating significant changes in each market sector.
- As part of our updated chapter on reactor capital upgrades, we have analyzed the potential impacts of nuclear plants operating up to 80 years. The possibility of "Life After 60" for numerous reactors could have huge implications for the global nuclear industry and the capital spending profile for the existing fleet.
- A brand new chapter on advanced and small modular reactors (SMRs) has been included for the first time in this edition of the NIVC. The SMR/AR market is extremely dynamic with considerable activity by existing reactor designers as well as numerous new entrants developing groundbreaking new technologies to fit an array of specialized energy applications.
- Given the high rate of reactor shutdowns in many parts of the world, the decommissioning chapter in this edition has been greatly expanded. This is one of the fastest growth sectors of the nuclear market, and it deserves increased attention.
- Enhanced data and modeling support all of the price and market size forecasts presented in this report for each sector. This new modeling relies on extensive research of empirical market data as well as expert UxC insights to provide the most accurate outlooks possible for the nuclear marketplace through 2035.

Structure of Report

This report includes separate chapters for the different market sectors in the nuclear industry. Given the structure of the nuclear energy markets, this report is split into four main parts as follows:

Part I – Nuclear Power in the World Today introduces the nuclear energy markets with a broad overview of all the main issues affecting the current state of nuclear power. This section reviews the history and current state of nuclear power, leading countries and technologies in the industry, as well as forecasts for future developments in nuclear power.

Part II – Front-End Market Overview provides a broad overview of the nuclear fuel cycle front-end markets with some initial market size forecasts for the entire front-end of the fuel cycle (i.e., uranium mining through fuel fabrication). **Chapter 1 – Uranium Mining and Milling** offers a detailed review of the uranium mining and milling market as it relates to the supply of uranium ore concentrate (U_3O_8 or "yellowcake"). **Chapter 2 – Uranium Conversion** covers the uranium conversion market (the chemical process of converting U_3O_8 to uranium hexafluoride or UF_6). **Chapter 3 – Uranium Enrichment** reviews and analyzes the current and future prospects of the uranium enrichment market (the service of separative work units or SWU for enriching natural uranium to low enriched levels necessary for light water reactor fuel). In **Chapter 4 – Nuclear Fuel Fabrication**, we provide a discussion of the fuel fabrication market (the manufacture of completed nuclear fuel assemblies), including both fresh uranium fuel as well as mixed oxide (MOX) fuel from reprocessed plutonium for light water reactors (LWRs) as well as non-LWRs.

Part III – Nuclear Reactor Market Overview looks at the largest of the nuclear energy market divisions: nuclear power plant construction and operations. It begins with **Chapter 5 – New Reactor Construction**, which covers the current and expected future status of the nuclear construction market with a focus on reactor vendors and the global reactor supply chain. In **Chapter 6 – Reactor Operations and Services**, we discuss the market for operations, services, and maintenance supplies for the current and expected future operating nuclear reactor fleet around the world. **Chapter 7 – Reactor Capital Upgrades** then provides a detailed analysis of the specific market for large capital upgrades for current and future operating reactors, focusing on major projects that are required to maintain safe and efficient operations of these plants over the long-term. **Chapter 8 – Advanced and Small Modular Reactors** presents an overview and analysis of the dynamic and rapidly evolving market for small modular reactors (SMRs) and advanced reactors (ARs).

Part IV – Back-End Market Overview provides an overview of the various nuclear fuel cycle back-end and radioactive waste management markets. **Chapter 9 – Spent Fuel Treatment, Storage and Disposal** reviews and analyzes the market for used or "spent" fuel reprocessing, storage, and disposal. This chapter has separate sections focused on each of these three spent nuclear fuel areas: treatment/reprocessing, storage, and disposal. **Chapter 10 – Radioactive Waste Management and Disposal**

offers our perspectives on the radioactive waste markets as focused on low-level and intermediate-level radioactive wastes (LLW and ILW). **Chapter 11 – Decontamination and Decommissioning** (D&D) covers the various aspects of the market for D&D of commercial/civilian nuclear facilities, which is often considered the final step in the nuclear value chain.

Ultimately, in **Part V – Summary and Conclusions**, we summarize our analysis of the overall nuclear industry value chain and consider future market prospects.

A number of additional useful items related to the various sectors and broader nuclear industry are found in the attached **Glossary** and **Appendices** at the end of the report. The appendices primarily consist of additional data collections, as follows:

Appendix A – UxC Nuclear Power Regions

Appendix B – Reactor Capacities Anticipated by 2035 by Country

Appendix C – Worldwide Reactors Under or Near Construction

Appendix D – Nuclear Reactor Supply Chain Companies

Appendix E – Nuclear Industry Alliances and Partnerships

