Uranium-Rare Earths Opening Address

OVERVIEW OF CURRENT GLOBAL URANIUM SUPPLY AND DEMAND AND INNOVATIONS REQUIRED FOR A SUSTAINABLE URANIUM INDUSTRY

By

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ABSTRACT

At the beginning of 2021, a total of 443 commercial nuclear reactors were connected to the electrical grid in 32 countries and globally an additional 52 reactors were under construction. Uranium demand is based on both the number of installed nuclear power plants as well as fuel cycle duration, enrichment level, burn-up and advanced fuel technologies.

Global uranium resources and production capability forecasts based on existing and committed production as well as planned and prospective capability, were reported in the joint OECD-NEA/IAEA Uranium Resources, Production and Demand (Red Book) 2020 publication. From a uranium resource perspective, according to the 2020 Red Book publication, total global recoverable identified conventional uranium resources are currently 8.1 million tonnes uranium and in-situ unconventional uranium resources amount to over 39 million tonnes of uranium. Low grade conventional and very low grade unconventional uranium resources (e.g., phosphate and black shale/schist) comprise a large part of this global uranium resource base.

At present, these low grade conventional and very low grade unconventional uranium resources are considered sub-economic to recover. However, these resources may be needed to meet demand requirements for uranium, since the 2020 Red Book analysis of uranium supply versus demand indicates a potential gap in supply from primary uranium producers in the coming decades. Therefore, mining and processing innovations will be required to ensure a sustainable supply of uranium in the future while meeting environmental and social acceptance requirements.

To reduce the environmental footprint of uranium recovery and improve the economics and social acceptance, many low grade conventional uranium projects are currently investigating innovative applications of in-situ recovery (ISR) of uranium. Examples may be found in sandstone type uranium deposits in China, Mongolia, and Russia. In Canada, ISR technology is being investigated in a Proterozoic unconformity type uranium deposit. If successful, this will be the first application of ISR in such deposits.

Other innovative approaches for improving the economics of uranium recovery from low grade and very low grade uranium resources may include the application of beneficiation techniques (e.g., gravimetric or radiometric) to increase the concentration of uranium in the feed to the processing facility, thereby potentially reducing unit operating costs and reducing the environmental footprint by decreasing the amount of tailings produced.

This presentation will provide additional detail on supply and demand forecasts for uranium based on the joint OECD-NEA/IAEA Uranium Resources, Production and Demand (Red Book) 2020 publication as well as provide a more detailed overview of potential innovative applications in the uranium mining and processing industry to ensure a future sustainable supply of uranium for nuclear power that meets social, environmental and economic requirements.

Keywords: Uranium, Mining, Supply, Demand, Sustainability, Innovation, In-Situ Recovery

Overview of Current Global Uranium Supply and Demand and Innovations Required for a Sustainable Uranium Industry

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1

Overview

- **Global Distribution of Nuclear Power Reactors**
- **Forecasted World Demand for Nuclear Power to 2040 and Uranium Requirements**
- **Global Uranium Supply and Demand projections to 2040**
- **Uranium Resources**
  - World Distribution
  - Total recoverable and in-situ identified conventional resources
  - In-situ unconventional resources
- **World Uranium Production**
  - Historical Production 1941 to 2021
  - Production by Mining methods (2016 to 2019)
  - Resources and Mining methods
- **Innovations in Mining and Processing (focusing on In-situ Recovery also known as In-situ Leaching)**

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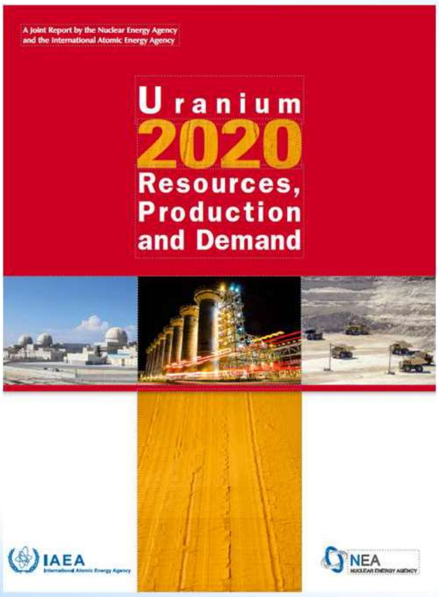
2

IAEA/NEA Red Book Publication (2020 Edition)



- Published since 1965
- A joint report by the NEA-OECD and the IAEA since 1969
- Widely recognized in the international nuclear community as a primary reference document on world uranium supply
- Available as a PDF free of charge: https://www.oecd-nea.org/jcms/pl_52718/uranium-2020-resources-production-and-demand
- Sources: governmental reports (via questionnaire), Secretariat reports and estimates
- WNA's Nuclear Fuel Report is published in alternate years
- Next edition of the Red Book (2022) is in progress

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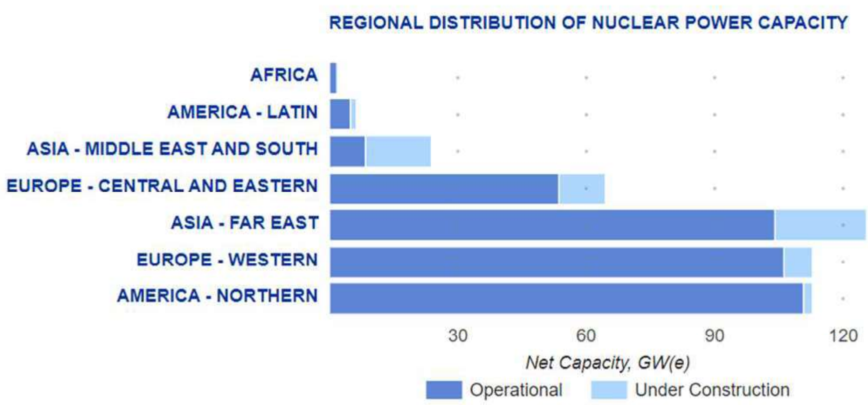
3

Global Distribution of Nuclear Power Reactors



Currently there are 441 Nuclear Power Reactors with a capacity 393.8 GW(e) operating in 32 countries

53 Reactors with a capacity of 54.5 GW(e) are under construction

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World projected installed nuclear capacity to 2040 (high and low projections, Red Book 2020)

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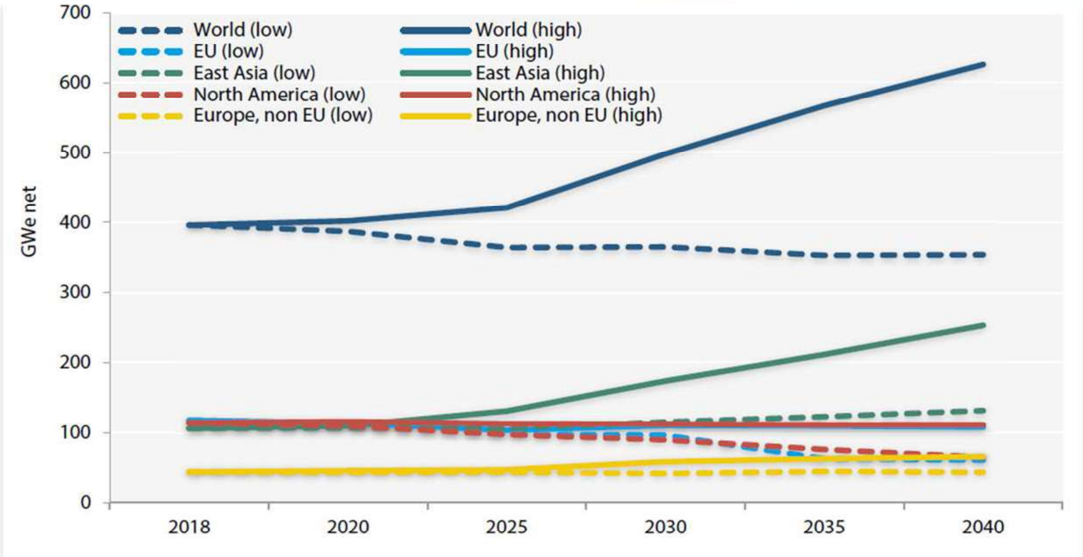

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5

Uranium Demand Forecast (high and low projections, Red Book 2020)

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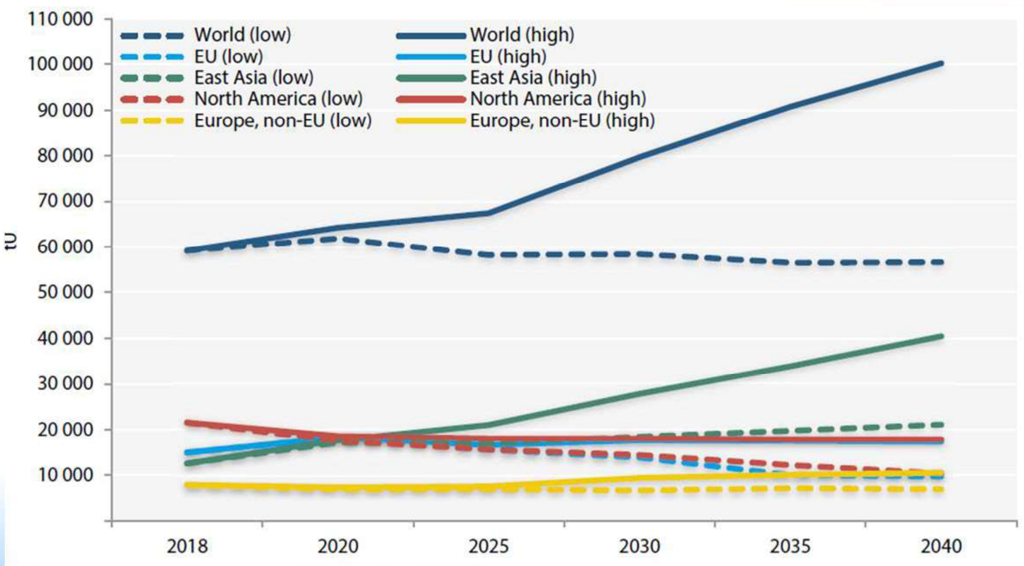

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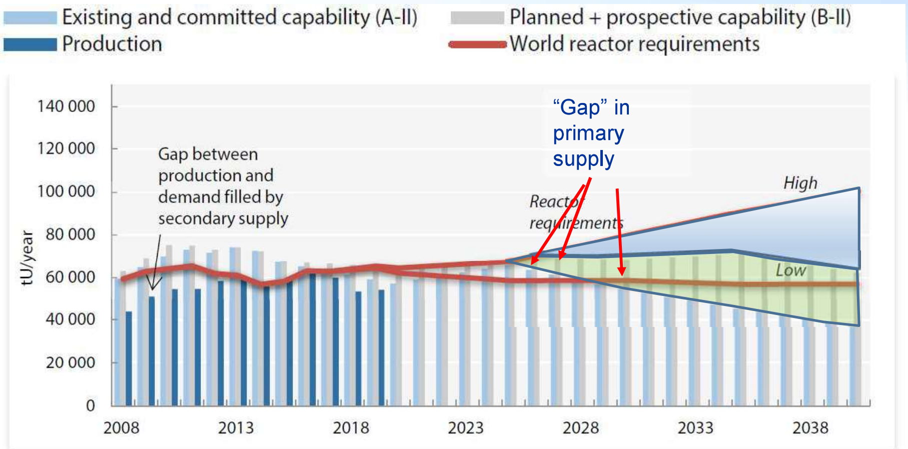
6

Global Uranium Supply and Demand to 2040*

***data from Red Book 2020**



Note this is the scenario at 85% total production (nameplate) capability. Includes all existing, committed, planned and prospective production capability centres supported by reasonably assured resources and inferred resources recoverable at a cost of <USD 130/kgU (USD 50/lb U_3O_8).

Note: does not include the secondary supply forecast

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7

Conventional and Unconventional Resources (Red Book 2020)

<u>Conventional Resources</u>

Established history of production where uranium is a primary product, co-product or an important by-product (e.g. mining of Cu and Au)

<u>Unconventional Resources</u>

Defined as very low-grade resources or those from which uranium is only recoverable as a minor by-product

Examples include:

- Phosphates
- Black shales
- Coal
- Heavy mineral sands

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Global Distribution of Identified Recoverable Uranium Resources (<USD 130/kgU as of 1 January 2019, Red Book 2020)

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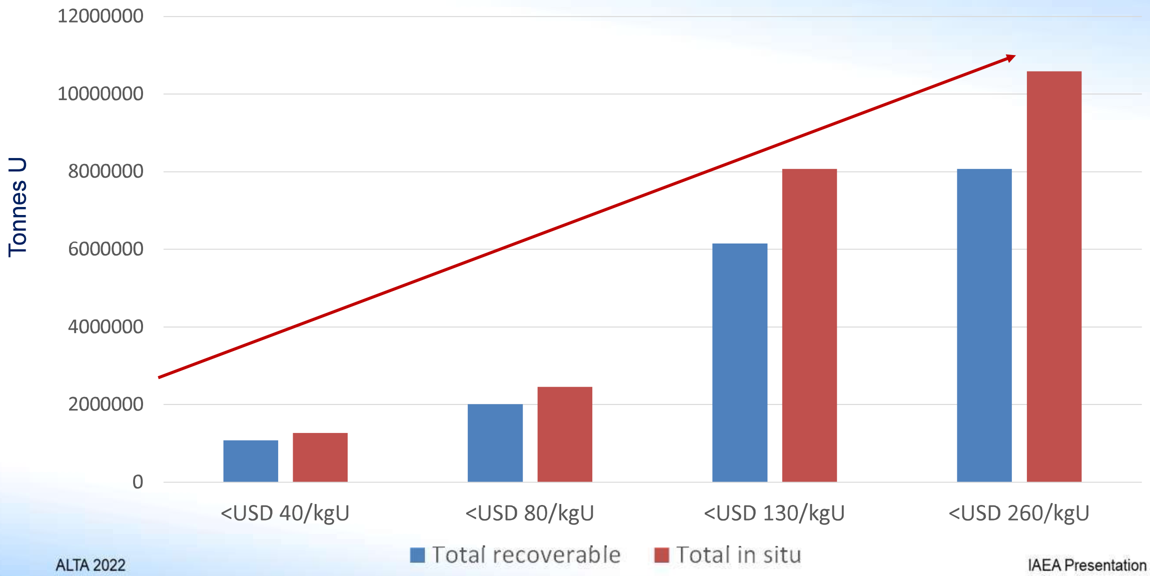
Total Recoverable and In-situ Identified Resources by cost category (Red Book 2020) approx. 8.1 Million tonnes U



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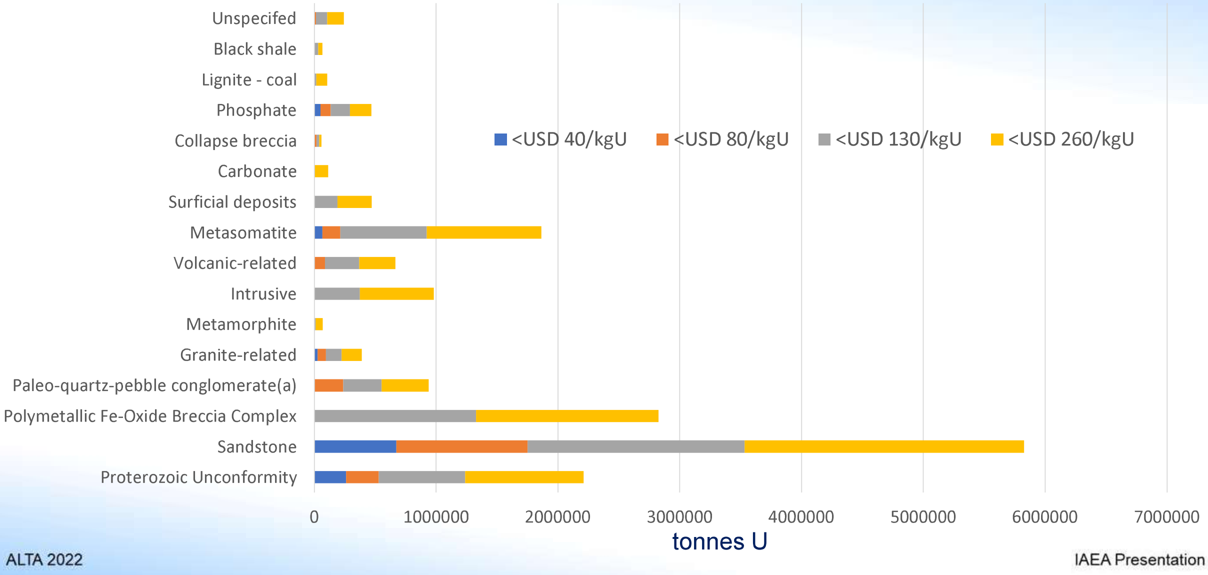
10

Global Total Identified Resources (recoverable) by Uranium Deposit Type (Red Book 2020)



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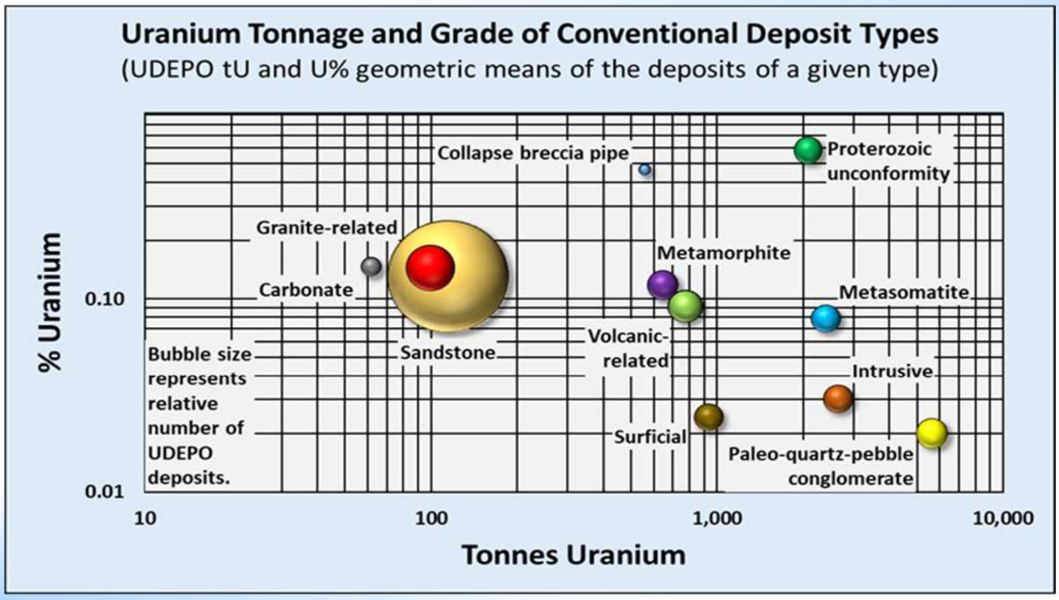
11

U Tonnages and Geometric Mean Grades for Important Uranium Deposit Types (Data source: IAEA Uranium Deposits Database, UDEPO 2021)



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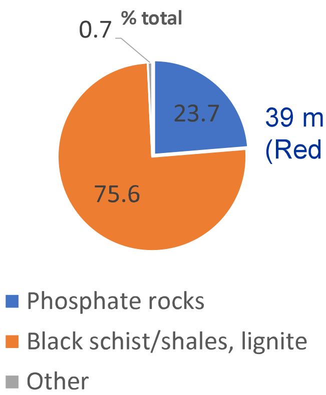
12

Unconventional Uranium Resources



39 million tonnes U (Red Book 2020)

On average unconventional resources are:
Very low grade (i.e. <0.10 %U)
high tonnage deposits (>100 000 tU)

Market conditions and technological development will be the main factors that determine the contribution of unconventional U resources to world production totals in the future

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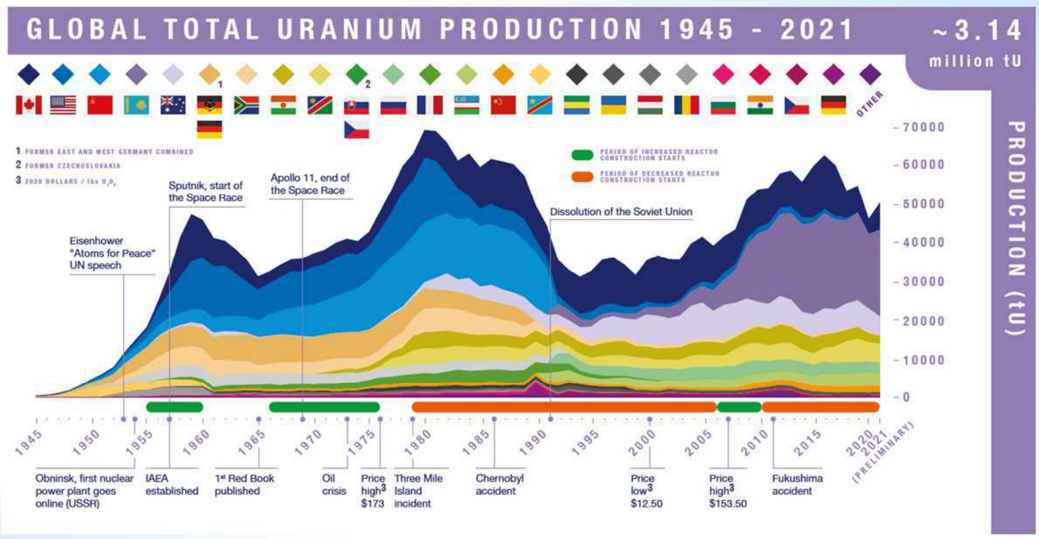
13

Global Uranium Production 1945 – 2021*



*Compiled by IAEA, 2021

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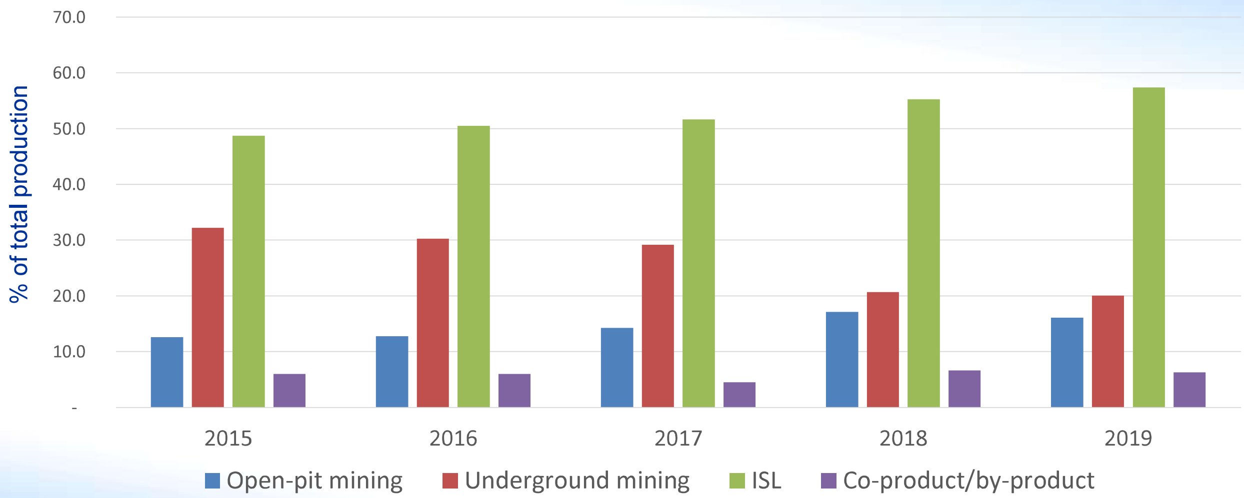
14

World Production by Mining Method 2015 – 2019 (Red Book 2020)



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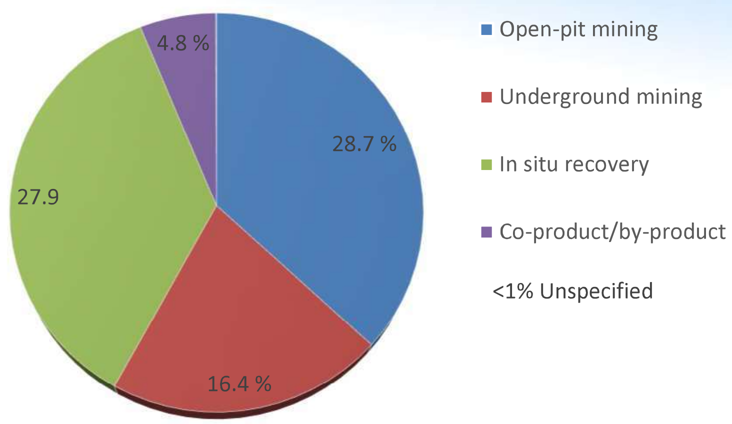
15

Identified Recoverable Resources by Forecasted Production Method as of 1 January, 2019 (Red Book 2020)



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16

Innovation Opportunities in the Uranium Mining and Processing Industry

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- Reduced mining costs
  - Innovations in in-situ recovery
    - Recovery of other elements
    - Applications of ISR to unconformity type deposits
    - Bioleaching
    - Mini-reagent technology
    - Modelling and simulation in development and management of ISL mining operations
  - Stope (block) leaching
- Pre-concentration of mined ores
  - Physical
  1. Chemical
- Advances in heap leaching technology for low grade ores
- Innovation in full life cycle issues, such as mine closure
- Unconventional resources: resolving potential security of supply issue

  Advances in chemical separation of U from phosphate ore

  Advances in recovery of U, Th and REEs from monazite and xenotime

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17

Innovations in In-situ Recovery

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18

By-product recovery of other elements

- Potential recovery of rare earth elements, scandium and rhenium from uranium sandstone deposits (ISR mining)
- Using sorption by cationic exchange resins or chemical precipitation methods, technologies to extract these commodities as by-products from pregnant uranium-bearing solutions are being developed at various ISR operations
- Rhenium was recovered in the mid-1980s during limited pilot applications at the Northern Kenimekh deposit in Uzbekistan and at some deposits in Kazakhstan (Kozhakhmetov et al., 2010)
- Scandium is currently being recovered as a by-product at the Dalur ISR operation in Russia

In situ recovery (leaching) of unconformity-type uranium deposits?

- Denison Mines is in the process of developing a modified, commercial-scale in situ leach (ISR) mining method at the company's Phoenix uranium deposit (27 000 tU; 19.1% U_3O_8) in Canada
- Existing and proven mining technologies have been used to create and test a novel application of the ISR mining method, which is typically used for low-grade sandstone hosted uranium deposits
- Includes the application of ground freezing technology to establish a physical form of containment (via a "freeze wall") around the deposit, the construction of an ISR wellfield within the freeze wall which will intersect the deposit at approximately 400 metres depth and the augmentation of natural hydrogeological flow paths in the ore body using permeability enhancement techniques
- Several significant environmental and permitting advantages, namely the absence of tailings generation, the potential for no water discharge to surface water bodies, and the potential to use the existing Provincial power grid to operate on a near zero carbon emissions basis

Photo: Denison Mines Wheeler River Project Camp

In situ bioleaching of sandstone-type uranium deposits

- Since the 1950s and 1960s, uranium was one of the first metals to be extracted by in situ and heap bioleaching methods
- At the 512 uranium deposit, located in the northwest of China, one of the largest in situ leach operations in China, two-stage bioleaching field experiments have been carried out since 2008 using a variety of injection and recovery well configurations
- Pilot tests revealed that uranium concentrations in the pregnant recovery solutions were 60%-170% higher compared to solutions recovered using conventional acid in situ recovery methods

Mini-reagent technology in ISR mining of sandstone-type uranium deposits

- In Uzbekistan and Kazakhstan, where uranium host sediments have a carbonate content of 1.8% to 3%, conventional acid ISR methods are economically inefficient because of excessive acid consumption and the active “plugging process” which results in decreased recovery rates for uranium
- Mini-reagent mining technology may help to alleviate this problem
- In mini-reagent technology, carbonates are dissolved and transformed into bicarbonate HCO_3^- which complexes with and transports U^{+6}
- During the process, sulphuric acid and oxidants react with carbonates raising the level of dissolved HCO_3^- in the recovery solutions to 300-400 mg/l, thus forming an excess of the complex-forming agent
- The agent oxidises and dissolves uranium-bearing minerals at the initial acidification stage, resulting in a “soft” mode of acid leaching, and producing a “bicarbonate effect”: the resulting recovery solutions have a pH of about 4 to 5

Modelling and simulation in development and management of ISR mining operations

- Modelling and simulation of the leaching process and its implementation has become an important factor when designing and managing an ISR mining operation
- Capital and operating costs can be reduced through:
  - optimisation of operating procedures;
  - improvement of decision-making and business planning quality and timeliness;
  - reduction of consumption of ISR reagents;
  - mining schedule optimisation; and
  - increasing the efficiency of uranium extraction

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23

Summary

- Global Uranium demand is expected to continue to increase in the next several decades
- Sufficient resources are identified, but pounds in the ground ≠ pounds in the can
- Long lead times for uranium mine development may result in a shortage of primary supply in the near term
- Security of supply is a key strategic consideration – which may also drive innovation for recovery of U from unconventional resources and currently uneconomic conventional resources
- Innovations in mining and processing is required to improve the economics of:
  - Low grade deposits, especially unconventional deposits (i.e. shales, phosphates)
  - Technically challenging deposits (i.e. at depth, U in refractory minerals, unstable ground due to structural, sedimentological constraints, applying new mining methods (i.e. ISR to unconformity type)
  - Improving recovery rates during processing and mining of currently uneconomic resources in all U deposit types regardless of grade

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24

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25

THANK YOU FOR YOUR ATTENTION

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26