World Uranium Resources, Supply and Demand

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Uranium Supply and Demand

- Uranium fundamentals
- Current supply and demand
- Major challenges to uranium production
- Future (potential) supply
  - Undiscovered resources
  - Unconventional resources
Uranium supply fundamentals

Primary Supply – Mined uranium

- Uranium mined as a primary product, co-product or important byproduct
- Tabulated as identified reasonably assured resources (RAR – roughly comparable to reserves) or potential (undiscovered) resources

Secondary Supply - Stocks and inventories of previously mined uranium in various forms (no reliable estimates of the volume of secondary supplies worldwide)

- **Military**
  - Megatons to Megawatts program - 20-year Russian- U.S. agreement converting weapons grade highly enriched uranium (HEU) to low-enriched uranium (LEU) that can be used in nuclear power plants
  - Produced 24 million pounds $U_3O_8$ (9,200 tU) LEU each year
  - Ended in 2013 – uranium from about 20,000 nuclear warheads was converted into about 10% of U.S. electricity supply during the 20 years of the program

- **Processing Tails**
  - Re-enriched tails
  - Tails are the product of the uranium enrichment process
  - Estimated 1.2 billion pounds $U_3O_8$ - 7 yrs. Of consumption at 2013 levels of demand

- **Reprocessed from Spent Reactor Fuel**
  - MOX (Mixed oxide) and (RepU) reprocessed uranium
  - Uranium and Plutonium recovered from spent fuel by reprocessing
  - Widely used in Europe, 21 reactors in France, 28 worldwide licensed to use MOX– beginning to be considered in the U.S.
World Uranium Supply/Demand

- 434 Operable Reactors (includes 48 in Japan currently offline), 100 in the U.S.
- Provides about 11% of electricity worldwide, 19% in the U.S. (2012 figures)
- 71 under construction: China - 28, Russia – 10, India – 6, S. Korea – 5, U.S. – 5, Slovakia, Pakistan, UAE – 2 each, Finland, France, Brazil, Argentina, Brazil – 1 each
- 173 planned (estimated 8-10 years until in operation) mostly in China, India and Russia

World:
- 2012 Demand
  - 176 million pounds U$_3$O$_8$ (67,990 tU)
- 2012 Production
  - 151 million pounds U$_3$O$_8$ (58,394 tU)

U.S.:
- 2012 U.S. Demand
  - 51 million pounds U$_3$O$_8$ (19,724 tU)
- 2012 U.S. Production
  - 4.1 million pounds U$_3$O$_8$ (1,596 tU)
Upper Supply Scenario:
Market is satisfied by rising supply to 2025, new mines are needed thereafter.

Lower Supply Scenario:
Lower demand projection covered until 2030; reference and upper case projections are not covered by existing supply.
Uranium supply
World U supply

![World Uranium Supply 2012](image)

- **Primary Supply**
  - Russia: 5%
  - Kazakhstan: 25%
  - Canada: 13%
  - Australia: 9%
  - Africa: 14%
  - Other countries: 3%

- **Secondary Supply**
  - Secondary Sources: 25%
  - U.S.: 1%
  - Ukraine: 1%
  - Uzbekistan: 3%
  - Other countries: 3%
  - Russian Govt. Stocks: 3%
  - Re-enriched Tails: 4%
  - Ru HEU/Feed: 4%
  - HEU/Feed (Cameco/Accara/Nukem): 6%
  - Enricher Sales: 2%
  - U.S. Govt. Stocks: 2%
  - Mox and RepU: 4%

- **World Uranium Production (tU) 2002-2012**
  - Data from the World Nuclear Association

- **Countries highlighted:**
  - USA
  - Canada
  - Australia
  - Kazakhstan
  - Namibia
  - Niger

World Nuclear Association, 2014,
UxConsulting uranium Suppliers Annual, 2013,
Uranium Supply - Security of Supply
Global distribution of identified resources - 2011

Uranium RAR mineable for < $50/pound U₃O₈ (< $130/kg U)

RAR of Uranium (tU) in IAEA Cost Categories

NEA/OECD-NEA 2011 Resources Production and Demand
World Nuclear Association, 2014
## Uranium Supply
### Vulnerabilities of supply

Top 10 mines produced 54% of world U supply in 2012

<table>
<thead>
<tr>
<th>Mine</th>
<th>Country</th>
<th>Main owner</th>
<th>Type</th>
<th>Production (million lbs. $\text{U}_3\text{O}_8$)</th>
<th>% of world U supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>McArthur River</td>
<td>Canada</td>
<td>Cameco</td>
<td>Underground</td>
<td>19.5</td>
<td>13%</td>
</tr>
<tr>
<td>Muyumkum/Tortkuduk</td>
<td>Kazakhstan</td>
<td>Katco JV/Areva</td>
<td>In-Situ Recovery</td>
<td>9.6</td>
<td>6%</td>
</tr>
<tr>
<td>Olympic Dam</td>
<td>Australia</td>
<td>BHP Billiton</td>
<td>By-product/underground</td>
<td>8.9</td>
<td>6%</td>
</tr>
<tr>
<td>Arlit</td>
<td>Niger</td>
<td>Somair/Areva</td>
<td>Open pit</td>
<td>8.0</td>
<td>5%</td>
</tr>
<tr>
<td>Ranger</td>
<td>Australia</td>
<td>ERA (Rio Tinto 68%)</td>
<td>Open pit</td>
<td>8.2</td>
<td>4%</td>
</tr>
<tr>
<td>Rossing</td>
<td>Namibia</td>
<td>Rio Tinto (69%)</td>
<td>Open pit</td>
<td>6.0</td>
<td>4%</td>
</tr>
<tr>
<td>Budenovskoye 2</td>
<td>Kazakhstan</td>
<td>Karatau JV/Kazatomprom-Uranium One</td>
<td>In-Situ Recovery</td>
<td>5.6</td>
<td>3%</td>
</tr>
<tr>
<td>Priargunsky</td>
<td>Russia</td>
<td>ARMZ/ Uranium One</td>
<td>Underground</td>
<td>5.2</td>
<td>3%</td>
</tr>
<tr>
<td>Langer Heinrich</td>
<td>Namibia</td>
<td>Paladin Energy</td>
<td>Surface</td>
<td>5.1</td>
<td>3%</td>
</tr>
<tr>
<td>South Inkai</td>
<td>Kazakhstan</td>
<td>Betpak Dala JV/Uranium One</td>
<td>In-Situ Recovery</td>
<td>4.9</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Top 10 total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>54%</strong></td>
<td></td>
</tr>
</tbody>
</table>

Accessibility to Resources
Are resources accessible?

- Two largest U.S. deposits - Mt. Taylor, in NM and Coles Hill, VA - are not easily accessible.
  - Coles Hill, VA (118 million lbs. $U_3O_8$) - state moratorium on uranium mining
  - Mt Taylor, NM (> 100 million lbs. $U_3O_8$) - Traditional Cultural Property

- Accessibility is a global concern
  - New U.N. classification system, requires not only economic and geologic certitude, but socio-economic viability of a resource
  - The new classification system is under review by IAEA and OECD member countries
  - Mapping of resources from the current to the new U.N. classification system will be included in the 2013 “Redbook”
Uranium Supply
Challenges to production
Long lag time from discovery to production

- 15-20 years from discovery to production
Uranium Supply
Challenges to Production
Increasing costs to discover and extract uranium

< $80/kgU = $30/lb U₃O₈
< $130/kgU = $50/lb U₃O₈
< $260/kgU = $100/lb U₃O₈

World Nuclear Association, 2014
Uranium Supply
Challenges to production
Lower uranium price

- Mines on standby status:
  - 2/7/2014 – Kayelekera mine in Malawi placed on care and maintenance
  - 2013-14 – Energy Fuels Inc. placed all U.S. mines on standby

- Delayed projects:
  - Areva delayed development of the Trekkopje mine in Namibia (projected to produce 5 million pounds of U₃O₈ by 2020), Bakouma in the Central African Republic, Imouraren in Niger (also security issues) and Ryst Kuil mine in S. Africa
  - BHP Billiton expansion of the Olympic Dam deposit in Australia will not proceed (production was expected in 2028 so only longer term projections are affected). Olympic Dam was to have brought about 50 million pounds of U₃O₈/year to the market by 2020
  - Cameco is cutting back global expansion plans – 2018 target now 36 rather than 40 million pounds of U₃O₈
  - Cameco will not develop Kintire (Proterozoic unconformity related) project in Australia (Jan, 2013)
  - 2012 – slowed expansion of Langer Heinrich in Namibia ( Paladin Resources)
  - Rio Tinto is cutting the workforce at Rossing Mine in Namibia by 17% (March, 2013)

- Short term: low prices are expected to persist as inventories remain high; as a result, more projects will likely be delayed or deferred, and less profitable mines placed on standby

USGS

UxConsulting, 2011
BHP-Billiton Ltd., 2012
Energy Fuels Inc., 2013
Long term potential uranium supply
Undiscovered Resources

Prognosticated Resources (in 1000 tU)

- Jordan
- Peru
- Mongolia
- Zambia
- Ukraine
- Indonesia
- Uzbekistan
- Bulgaria
- India
- South Africa
- Canada
- Russian Federation
- Brazil
- Kazakhstan
- United States

Million Pounds U₃O₈

- tU in the cost range < $80/kgU
- tU in the cost range < $130/kgU
- tU in the cost range < $260/kgU

< $80/kgU = $30/lb. U₃O₈
< $130/kgU = $50/lb. U₃O₈
< $260/kgU = $100/lb. U₃O₈

NEA/OECD-NEA 2012
Long term potential uranium supply
Undiscovered Resources

Speculative Resources (in 1000 tU)

- Niger
- Germany
- Venezuela
- Czech Republic
- Colombia
- Vietnam
- Kazakhstan
- Ukraine
- Brazil
- Canada
- Russian Federation
- South Africa
- United States
- Mongolia

Million Pounds U₃O₈
0 500 1040 1560 2080 2600 3120 3640

- tU in cost range <$130/kgU
- tU in cost range <$260/kgU
- tU Cost range unassigned

< $80/kgU = $30/lb. U₃O₈
< $130/kgU = $50/lb. U₃O₈
< $260/kgU = $100/lb. U₃O₈
Domestic Uranium Supply
U.S. Uranium Reserves ~10 years of U.S. Supply (2013 demand)

U.S. Energy Information Administration Estimates of Uranium Reserves by State, Year-End 2008

<table>
<thead>
<tr>
<th>Million Pounds $50/pound U3O8 Forward Cost Category (Million Pounds)</th>
<th>Wyoming</th>
<th>New Mexico</th>
<th>Arizona, Colorado, Utah</th>
<th>Texas</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50/pound U3O8 Forward Cost Category (Million Pounds)</td>
<td>220</td>
<td>179</td>
<td>63</td>
<td>27</td>
<td>50</td>
</tr>
<tr>
<td>$100/pound U3O8 Cost Category (Million Pounds)</td>
<td>446</td>
<td>390</td>
<td>198</td>
<td>40</td>
<td>154</td>
</tr>
</tbody>
</table>

EIA, 2010
Domestic Uranium Supply
U.S. Uranium Mines - 2014

- ISR:
  - Crow Butte, NE (Cameco)
  - Smith Ranch/Highland, WY (Cameco)
  - North Butte, WY (Cameco)
  - La Palangana, TX (Uranium Energy Corporation)
  - Alta Mesa, TX (Mestena Uranium)
  - Willow Creek, WY (ARMZ/Uranium One)
  - Lost Creek, WY (ISR – UR Energy)

- Conventional:
  - All permitted mines on standby
  - White Mesa Mill will discontinue production in August, 2014

- Close to production:
  - Nichols Ranch/Hank, WY (ISR- Uranerz) under construction
  - Goliad, TX (ISR - Uranium Energy Corporation) under construction
Domestic Uranium Supply
Long Term Potential Uranium Supply
Undiscovered Resource Assessments

- Last full U.S. assessment of undiscovered resources completed in 1980
- USGS started re-assessing domestic undiscovered U resources in 2013
- Assessments of resources that will impact the total uranium endowment of the U.S. are being prioritized
- Land use and energy policy support

<table>
<thead>
<tr>
<th></th>
<th>Forward-cost category</th>
<th>Million Pounds U₃O₈</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>$30/pound U₃O₈</td>
<td>Reserves</td>
<td>1,419</td>
</tr>
<tr>
<td></td>
<td>Probable</td>
<td>1,947</td>
</tr>
<tr>
<td></td>
<td>Possible</td>
<td>761</td>
</tr>
<tr>
<td></td>
<td>Speculative</td>
<td>684</td>
</tr>
<tr>
<td>$50/pound U₃O₈</td>
<td>Reserves</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Probable</td>
<td>2,059</td>
</tr>
<tr>
<td>$100/pound U₃O₈</td>
<td>Reserves</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Probable</td>
<td>3,137</td>
</tr>
<tr>
<td></td>
<td>Possible</td>
<td>1,410</td>
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<tr>
<td></td>
<td>Speculative</td>
<td>1,060</td>
</tr>
</tbody>
</table>

DOE, 1980
Long term potential uranium supply
Top priority USGS undiscovered resource assessments

- Metasomatic/SE Shear Zone deposits
  - Coles Hill, VA largest undeveloped uranium deposit in the U.S. with reported RAR of more than 100 million pounds of U$_3$O$_8$
  - Resource potential not previously assessed
  - Large international endowment, 4$^{th}$ most prolific class of deposit.
  - Could have a significant impact the U.S. resource endowment

IAEA, 2010
Long term potential uranium supply
Top priority USGS undiscovered resource assessments

Calcrete Uranium

- Large deposits in Australia and Namibia
- 900 million pounds U$_3$O$_8$ in resources (351,000 tU) worldwide
- Relationship between latitude & uranium provinces
- Fairly well understood deposit controls
- Why none in the U.S.?
Long term potential uranium supply
Top priority USGS undiscovered resource assessments

- Unconformity Type U deposits
  - Large international endowment, none recognized in the U.S.
  - Deposit controls now fairly well understood
  - Not well understood during last domestic assessment so not assessed
Long term potential uranium supply
Top priority USGS undiscovered resource assessments

Phosphate Byproduct uranium potential

- Phosphate is mined for fertilizer
- In the U.S. averages 100-130 ppm U This U is currently not recovered
- Rough estimates indicate that there are ~2 billion pounds U₃O₈ (765,000 tU) possible resources in phosphates located in Florida & Idaho
- 200 billion pounds U₃O₈ (7.9 billion tU) worldwide

IAEA, 2010
OECD-NEA/IAEA 2012
Long term potential uranium supply
Top priority USGS undiscovered resource assessments

Sandstone-hosted deposits (Roll-front, Tabular and Basal Channel)

- Largest existing resource is being actively mined
- Not a high priority assessment because deposit controls were thoroughly studied in earlier assessments
- Proof of concept assessment underway in the TX Gulf Coast region to see if estimation techniques used now are more predictive than in the last domestic assessment
- May reassess sandstone deposits based on outcome of TX proof-of-concept study
Long term potential uranium supply – Unconventional Uranium from seawater

- Research carried out from 1950s – 1980s
- Last published economic study by Japan
- Not economic to extract
  - Direct costs of extraction are $ 55 to $ 330 per pound of U₃O₈ plus capital costs of 1 billion $ for a 3 million pound U₃O₈/year plant
- Notwithstanding these obstacles, the U.S. Department of Energy began evaluating Japanese research, and funding additional research in 2011
- Other issues: braid replacement, maritime legal constraints, disposal of significant quantity of absorbent material
Alternatives to uranium - Thorium reactors

- Thorium (Th) can be used as a nuclear fuel
- Past research on Th reactors has been carried out by Germany, UK, Canada, U.S., India. Current research in India, China, Canada, Norway.
- No commercial reactor in currently operating
- Because of low demand – Th has not been a primary exploration target
- Th resources in the U.S. are likely to be obtained as a byproduct of rare earth element (REE) mining
  - 3 REE deposits in the U.S. have been identified as containing significant Th within the REE deposit; Mountain Pass, CA; Bear Lodge project, WY; Bokan Mountain, AK
  - Adequate domestic supplies of Th are thought to exist for potential requirements under under current build-out scenarios for Th-based reactors