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$_3$O$_8$ (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$_3$O$_8$ - 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 U₃O₈ (67,990 tU)
- 2012 Production
  - 151 million pounds U₃O₈ (58,394 tU)

U.S.:
- 2012 U.S. Demand
  - 51 million pounds U₃O₈ (19,724 tU)
- 2012 U.S. Production
  - 4.1 million pounds U₃O₈ (1,596 tU)

NEA/OECD-NEA 2011 Resources Production and Demand
World Nuclear Association, 2014
Global Supply/Demand Projection to 2030
World Nuclear Association

**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

Primary Supply
- Russia 5%
- Kazakhstan 25%
- Canada 13%
- Australia 9%
- Africa 14%

Secondary Sources 25%
- Ukraine 3%
- U.S. 3%
- Uzbekistan 3%
- Other countries 3%

Secondary Supply
- Russian Govt. Stocks 3%
- Re-enriched Tails 4%
- Ru HEU Feed 4%
- HEU Feed [Cameco/Aera/Nukem] 4%
- Enricher Sales 3%
- U.S. Govt. Stocks 2%
- Mox and RepU 4%

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

Million Pounds U3O8

USA
Namibia
Niger
Australia
Canada
Kazakhstan

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

- < $15 /pound U₃O₈
- $15-30 /pound U₃O₈
- $30-50 /pound U₃O₈
- $50-80 /pound U₃O₈

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. U$_3$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>

World Nuclear Association, 2014,
UxConsulting Uranium Suppliers Annual, 2013
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”

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NEA/OECD-NEA 2012
Kyle and Beahm, 2013
Rio Grande Resources, 2014
UNECE, 2010
Uranium Supply
Challenges to production
Long lag time from discovery to production

- 15-20 years from discovery to production

Vance, 2005
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 $U_3O_8$ 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 $U_3O_8$/year to the market by 2020
  - Cameco is cutting back global expansion plans – 2018 target now 36 rather than 40 million pounds of $U_3O_8$
  - 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

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

Values are in Million Pounds U₃O₈:
- < $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

- 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></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>Forward-cost category</th>
<th>Million Pounds U₃O₈</th>
<th>Probability distribution values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>95th percentile</td>
</tr>
<tr>
<td>Reserves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$30/pound U₃O₈</td>
<td>1,419</td>
<td>1,247</td>
</tr>
<tr>
<td>Probable</td>
<td>1,947</td>
<td>1,450</td>
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<tr>
<td>Speculative</td>
<td>761</td>
<td>427</td>
</tr>
<tr>
<td>Speculative</td>
<td>684</td>
<td>341</td>
</tr>
<tr>
<td>$50/pound U₃O₈</td>
<td>2,059</td>
<td>1,806</td>
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<tr>
<td>Probable</td>
<td>3,137</td>
<td>2,424</td>
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<tr>
<td>Speculative</td>
<td>1,410</td>
<td>761</td>
</tr>
<tr>
<td>Speculative</td>
<td>1,060</td>
<td>552</td>
</tr>
<tr>
<td>$100/pound U₃O₈</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reserves</td>
<td>2,468</td>
<td>2,136</td>
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<tr>
<td>Probable</td>
<td>4,576</td>
<td>3,621</td>
</tr>
<tr>
<td>Speculative</td>
<td>2,211</td>
<td>1,146</td>
</tr>
<tr>
<td>Speculative</td>
<td>1,531</td>
<td>832</td>
</tr>
</tbody>
</table>
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 $\text{U}_3\text{O}_8$
  - Resource potential not previously assessed
  - Large international endowment, 4th 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 $U_3O_8$ 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 $U_3O_8$ (765,000 tU) possible resources in phosphates located in Florida & Idaho
- 200 billion pounds $U_3O_8$ (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 $U_3O_8$ plus capital costs of 1 billion $ for a 3 million pound $U_3O_8$/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

NEA/OECD-NEA 2012
Tamada, 2006, 2009
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
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