Building the Bridge from Both Ends: Comprehensive Extraction and Zero Waste Strategies for NORM Industry Tailings and Residues

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The terms

- **Sustainability**: The capacity of the present generation to meet its needs without compromising or impairing the ability of future generations to meet theirs.

- **Comprehensive extraction (CX)**: “comprehensive extraction† and conservation of earth’s mineral reserves and resources”* - all resources are co-products.

- **Zero waste (0W)**: Zero waste.

- **Innovation**: New capabilities through continuous improvement or creative disruption.

- **Beneficiation**: Making resources better or making better resources – the rise of the co-product and the by-product.

- **Value stream release**: The development and use of new economic resources from “residuals” (System of Environmental-Economic Accounting (SEEA)).


† Dr. Pingru Zhong, IAEA Technical Meeting on Uranium from Unconventional Resources, September 2011.
The terms of the new equilibrium

Sustainability

Comprehensive extraction + Zero waste
Innovation + Beneficiation
Sustainability

Innovation

Beneficiation

Value Stream

CX

0W
Proof of concept: UxP

Uranium...

... Phosphate

... co-products across their life-cycles

Challenging the boundaries of “conventional” and “unconventional” resource provenance
CX

Co-Products
Single Mineral or Complex Resource?

What do I see?
What do I see?

- Phosphate Rock
- Phosphoric Acid
- Purified Acid
- Phosphogypsum
- Yellow Cake
- Phosphate Fertiliser
- Rare Earths
- Sulphur
- Ammonium Sulphate

What else?
The world’s largest uranium mine is a copper mine.

The world’s largest uranium deposit is a phosphate “province.”
OW

“The Release of Residuals”
Tailings and Residues
PHOSPHATE ROCK:

Primary resource – 25% $\text{P}_2\text{O}_5$
PHOSPHATE MINE TAILINGS:

“Waste” – 25% $\text{P}_2\text{O}_5$
What am I looking at?

Phospho-gypsum: Waste or Resource?
Innovation and Beneficiation
Constructive Regulation: Co-products of phosphate
Phosphogypsum is an affordable, safe Soil Amendment, construction resource etc etc - not a Waste
Secondary Resources and Comprehensive Extraction

1. What are Secondary mineral resources?
   – by-product in mining
   – by/co-product from reprocessing of waste, tailings and residues
   – by/co-product arising from clean-up of materials
   – by/co-product for environmental management activities, such as environmental remediation

2. Advantages in recovery
   – improves the recovery of main product, or other co-products
   – open avenues to CX - recovery of many other materials
   – produce cleaner down stream products
   – introduces innovative technologies that can have spin-off benefits
   – positive benefits on the health, safety and environment

3. Unconventional uranium resources are often 6-7 x more
   – Proper assessment, classification and management using UNFC-2009 required
   – Supply depends on a successful CX business model

4. Traditional mining mindset needs to change?
   – See only one target material not enough?
Some past experiences with U

• By product of Copper
  – Bingham Canyon, USA, 1978-89, 2-15 ppm, 50 tU/y
  – Twin Buttes, Arizona, USA, 100 tU/y
  – Yerington, Nevada, USA

• Polymetallic Iron Oxide Breccia Complex
  – Olympic Dam, Australia (Currently, ongoing co-product of Cu and Ag - 3 353 tU/y)

• Carbonatite
  – Phalabora, South Africa – until 2001 640 tU (30-40 ppm) as by-product of Cu, etc

• Coal-lignite
  – Freital-Gittersee deposit, Germany, 3 700 tU, 0.12% U
  – Dakota Plains, USA
  – Min-Kush, Kyrgyzstan

• Paleo quartz pebble conglomerate Au – U
  – Continues in South Africa

• Phosphate
  – Florida, USA, 17 500 tU (1978 – 1991)
  – Belgium (from Moroccan phosphate rock)

• Shale
  – Schmirchau-Reust, Drosen, Paitzdorf, Germany
Comprehensive extraction

• Mining in general is seeing declines in capital and labour productivity – mostly due to decline in ore grades combined with upgradation of mining infrastructure.

• Comprehensive extraction in 1990s looked into technical feasibility of extraction form lower grade and other uneconomical resources.

• Now it is seen as a way to improve overall economics and address health, safety and environmental issues.

Change in mindset

Mostly overlooked Columbite from Pitinga project, Brazil (Mineração Taboca)

Currently produces Sn; and minor Nb, Ta (6.5% recovery). Has decided to produce additional Ta, Nb, Y, REE, U and Th by 2020.
## Future possibilities for U (1/2)

<table>
<thead>
<tr>
<th>No</th>
<th>Country</th>
<th>Project</th>
<th>Operator</th>
<th>Deposit type</th>
<th>Materials recovered</th>
<th>Nominal production capacity (tU/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Australia</td>
<td>Nolans Bore</td>
<td>Arafura Resources</td>
<td>Intrusive/Peralka line complex</td>
<td>REE, P, Th, U</td>
<td>130</td>
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<tr>
<td>2</td>
<td>Greenland</td>
<td>Kvanefjeld</td>
<td>Greenland Minerals and Energy Limited</td>
<td>Intrusive/Peralka line complex</td>
<td>REE, U, Zn, Flurospar</td>
<td>425</td>
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<tr>
<td>3</td>
<td>Malawi</td>
<td>Kanyika</td>
<td>Globe Metals and Mining</td>
<td>Intrusive/Peralka line complex</td>
<td>Nb, Ta, Zr, U</td>
<td>60</td>
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<tr>
<td>4</td>
<td>Brazil</td>
<td>Pitinga</td>
<td>Mineração Taboca</td>
<td>Intrusive/Peralka line complex</td>
<td>Sn, Nb, Ta, REE, Th, U</td>
<td>?</td>
</tr>
<tr>
<td>5</td>
<td>Chile</td>
<td>Chuquicamata</td>
<td>CCHEN - CODELCO Norte</td>
<td>Intrusive/Quartz monzonite</td>
<td>Cu, U, Mo</td>
<td>85</td>
</tr>
<tr>
<td>6</td>
<td>Sweden</td>
<td>Häggån</td>
<td>Aura Energy</td>
<td>Black Shale</td>
<td>U, Ni, Mo</td>
<td>3000</td>
</tr>
<tr>
<td>7</td>
<td>Finland</td>
<td>Talvivaara</td>
<td>Talvivaara Sotkamo Ltd</td>
<td>Black Shale</td>
<td>Ni, Zn, Cu, Co, U</td>
<td>350*</td>
</tr>
</tbody>
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## Future possibilities for U (2/2)

<table>
<thead>
<tr>
<th>No</th>
<th>Country</th>
<th>Project</th>
<th>Operator</th>
<th>Deposit type</th>
<th>Materials recovered</th>
<th>Nominal production capacity (tU/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Morocco</td>
<td></td>
<td>OCP</td>
<td>Phosphate</td>
<td>U</td>
<td>1900</td>
</tr>
<tr>
<td>9</td>
<td>USA</td>
<td>Plant City</td>
<td>CF</td>
<td>Phosphate</td>
<td>U</td>
<td>2680</td>
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<tr>
<td>10</td>
<td>Brazil</td>
<td>Santa Quitéria</td>
<td>INB – Galvani JV</td>
<td>Metamorphite/Marble hosted Phosphate</td>
<td>P, U, Th</td>
<td>970</td>
</tr>
<tr>
<td>11</td>
<td>South Africa</td>
<td>TPM Uranium Project</td>
<td>Harmony Gold</td>
<td>Paleo Quartz-pebble conglomerate</td>
<td>Au, U</td>
<td>340</td>
</tr>
<tr>
<td>12</td>
<td>South Africa</td>
<td>Free State Tailings Uranium Project</td>
<td>Harmony Gold</td>
<td>Paleo Quartz-pebble Conglomerate tailings</td>
<td>U</td>
<td>700</td>
</tr>
<tr>
<td>13</td>
<td>South Africa</td>
<td>Springbok Flats (Settlers area)</td>
<td>HolGoun Uranium &amp; Power</td>
<td>Coal-lignite</td>
<td>Coal, U</td>
<td>600</td>
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<tr>
<td>14</td>
<td>Canada</td>
<td>Eco Ridge</td>
<td>Pele Mountain Resources</td>
<td>Paleo-quartz pebble conglomerate</td>
<td>REE, Sc, Eu, Gd, U</td>
<td>~950</td>
</tr>
</tbody>
</table>
# The Co-product Options

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Number of reported world deposits</th>
<th>Number of U deposits recorded in UDEPO</th>
<th>Total Resources in UDEPO (t U)</th>
<th>Average Grade (ppm U)</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| 1  | Intrusive (Carbonatite, Peralkaline, Plutonic, Quartz monzonites)    | 646 – Porphyry copper deposits \(a\)  
                              |                                   | 125 – Peralkaline complex \(b\)      | 5027 – Carbonatites \(c\)      | 33                    | 896 883                          | 40 – 6 400                       | REE, Nb, Ta, Zr, U, Cu, Au, Ag, Mo |
| 2  | Polymetallic Iron Oxide Breccia Complex                              | 33\(d\) (numerous \(e\))          | 16                                     | 2 438 773                      | 60 - 850              | Cu, Au, Ag, U                   |
| 3  | Lignite-coal                                                         | 2700\(f\) (23 057 billion tonnes Reserves + Resources \(g\)) | 35                                     | 7 388 122                      | 20 – 1 700            | U, Ge                           |
| 4  | Phosphate                                                            | 1635\(h\) (300 billion tonnes \(i\)) | 57                                     | 14 058 525                     | 10 – 3 033            | P, S, Sc, F, REE, U              |
| 5  | Black shale                                                          | 64\(j\)                           | 50                                     | 20 963 792                     | 17 - 1200             | Ni, Co, Cu, U                   |
| 6  | Paleo quartz-pebble conglomerate (Au dominant)                      | 64\(k\)                           | 25                                     | 467 342                        | 30-80                 | Au, U                           |
|    | Paleo quartz-pebble conglomerate (U dominant)                       |                                    |                                        |                                |                       |                                  |
| 7  | Heavy mineral sands                                                  | 77\(l\)                           |                                        |                                |                       | REE, Ti, Th, Zr, Sn             |
| 8  | Lignite-coal ash                                                     | 21 billion tonnes \(m\)           |                                        |                                |                       | U, Ge, Mo, etc                  |
| 9  | Mine tailings                                                        |                                    |                                        |                                |                       | Multiple, U                     |
| 10 | Mine wastes                                                          |                                    |                                        |                                |                       | Multiple, U                     |
| 11 | Mine water                                                           |                                    |                                        |                                |                       | Multiple, U                     |
| 12 | Phosphogypsum                                                        | 2.6 – 3.7 billion tonnes \(n\)     |                                        |                                |                       | REE, F, S, U                    |
| 13 | Metal slags                                                          |                                    |                                        |                                |                       | Sn, Nb-Ta slags with U          |
| 14 | Sea water                                                            |                                    |                                        | 4 500 000 000                  | 3.3 ppb               | Multiple, U                     |

Total (excluding seawater) 47 883 584

\(a\) Singer. et.al. 2005; \(b\) Orris and Grauch, 2002; \(c\) Woolley and Kjarsgaard, 2008; \(d\) – Cox and Singer, 2007; \(e\) Barton, 2014; \(f\) IHS Global Coal Database; \(g\) BGR, 2014; \(h\) Chernoff, 2002; \(i\) – USGS, 2015; \(j\) – including gold tailings, S. Africa; \(k\) – ThDEPO; \(l\) – Monnet, 2014; \(m\) – IAEA, 2013
**UxP – The Co-product Option**

### Unconventional U

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite (2%)</td>
<td>313,685</td>
</tr>
<tr>
<td>Black Shale (8%)</td>
<td>1,199,086</td>
</tr>
<tr>
<td>Other (2%)</td>
<td>234,137</td>
</tr>
<tr>
<td>Phosphates (88%)</td>
<td>12,894,830</td>
</tr>
</tbody>
</table>

**Total** 14,641,738

*UDEPO, 2012*
UxP - U as P co-products for energy and food
Resource Sustainability: the New Equilibrium
Building the bridge to the future from both ends

CX The Social Licence to Operate OW
Thank you for your kind attention

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