2016 Rio norm VIII CHALLENGES AND SOLUTIONS

IAEA 60 Years Atoms for Peace and Development

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))

*TRUBETSKOY, K.N., Mining Sciences: Development and Conservation of the Mineral Resources of the Earth, Academy of Mining Sciences, Moscow (1997).

† 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

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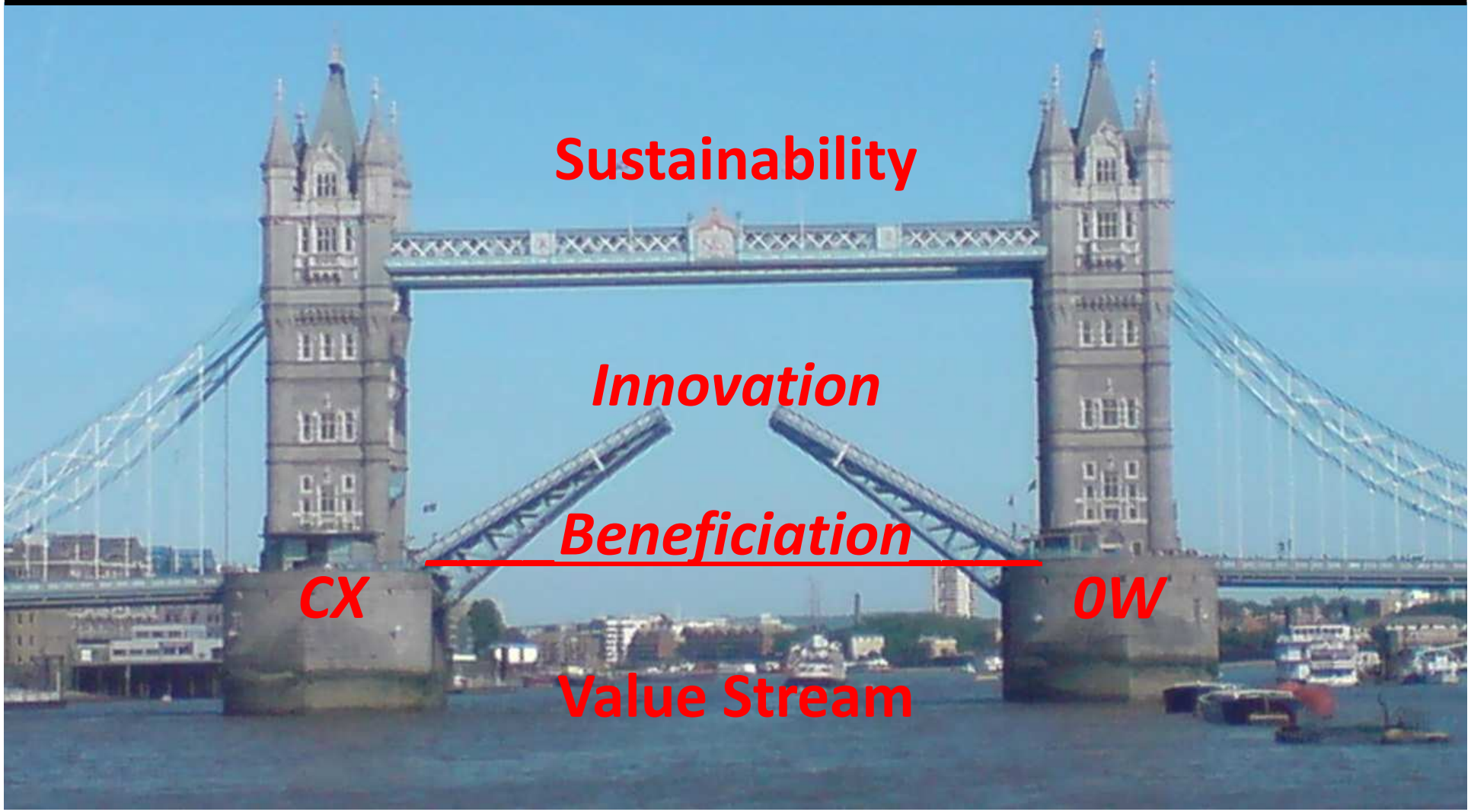
CHALLENGES AND SOLUTIONS



Proof of concept: UxP

Uranium…

… Phosphate

… co-products across their life-cycles

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

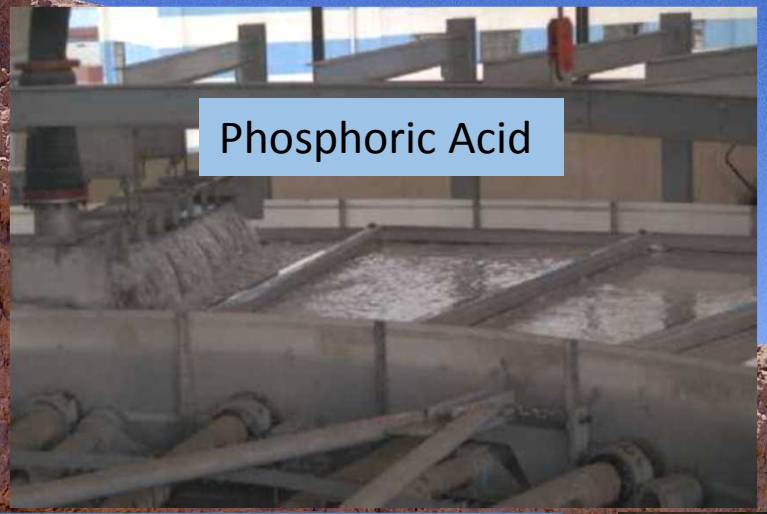
CX

Co-Products


Single Mineral or
Complex Resource?
What do I see?

What do I see?

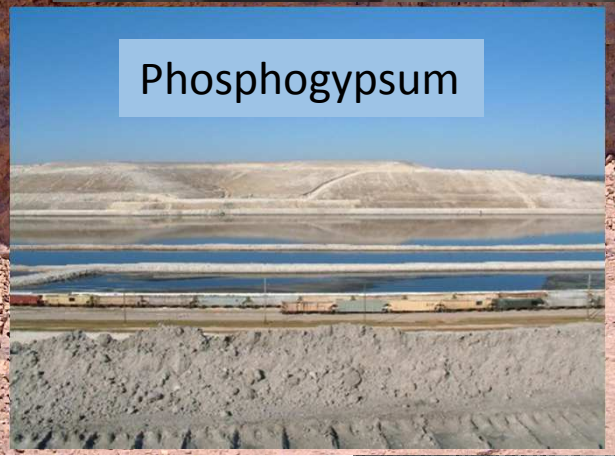
Phosphate Rock



Phosphoric Acid

Purified Acid

Phosphate Fertiliser



Phosphogypsum

Yellow Cake

Rare Earths

Sulphur

Ammonium Sulphate

?

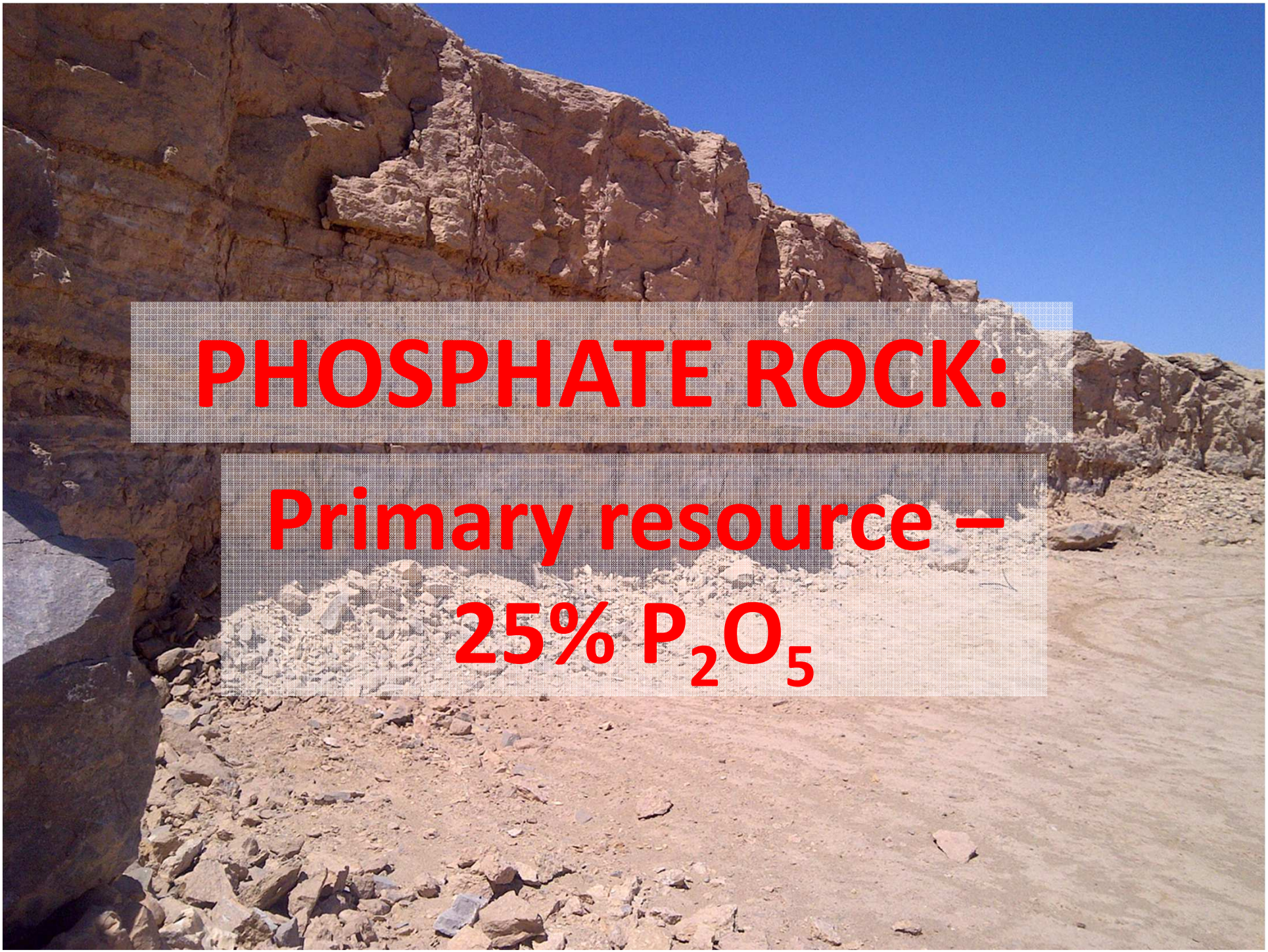
What else?

CONVENTIONAL OR UNCONVENTIONAL?

0W

“The Release of Residuals”

Tailings and Residues

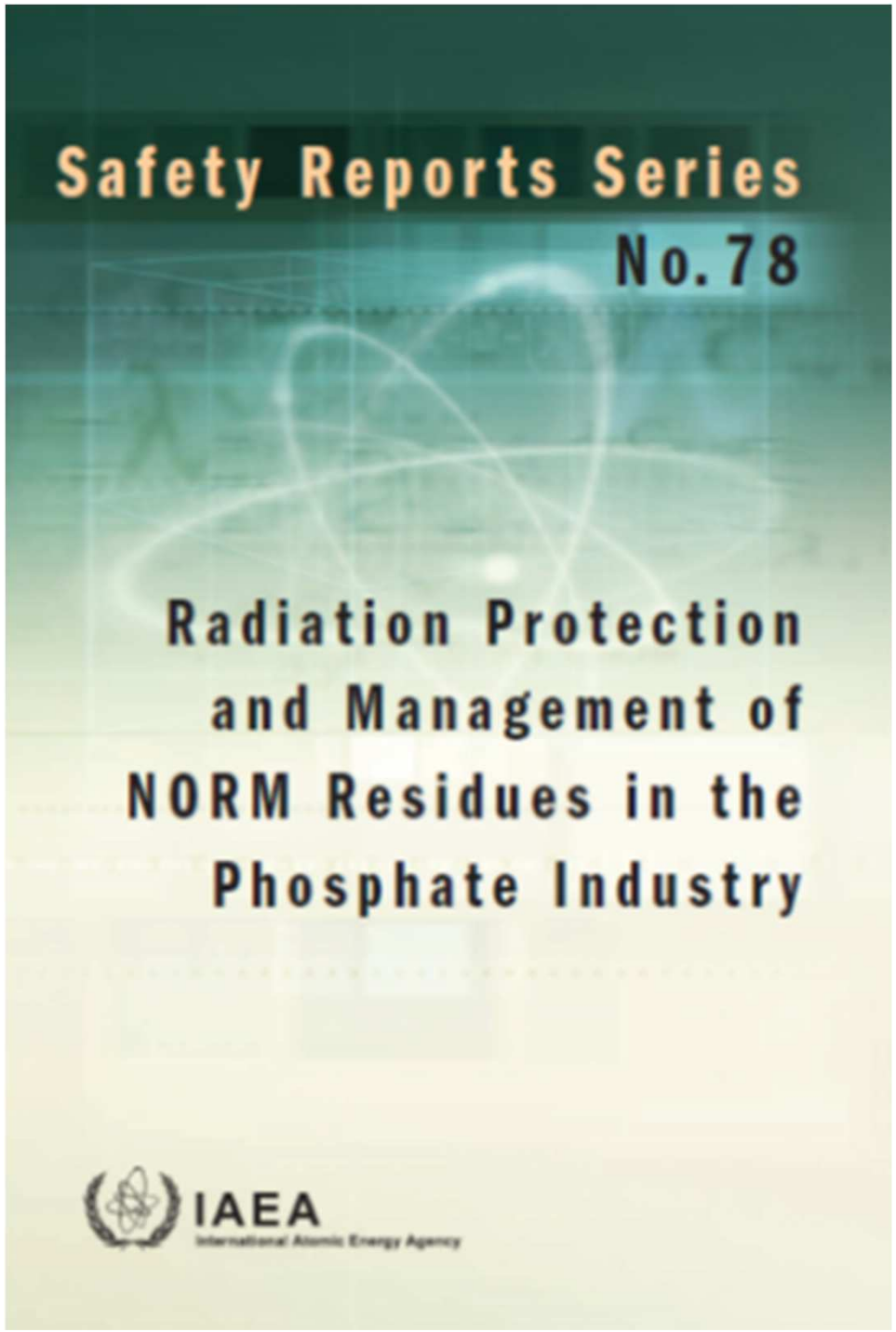

PHOSPHATE ROCK:
Primary resource –
25% P_2O_5


PHOSPHATE MINE TAILINGS:
"Waste"– 25% P_2O_5


PROCESSING RESIDUES
What am I looking at?
Phospho-gypsum:
Waste or Resource?

Innovation and Beneficiation

Constructive Regulation: Co-products of phosphate



Does it go here?

Does it go here?

Phosphogypsum is an affordable, safe Soil Amendment, construction resource etc etc - not a Waste

Does it go here?

Does it go here?

Secondary Resources and Comprehensive Extraction

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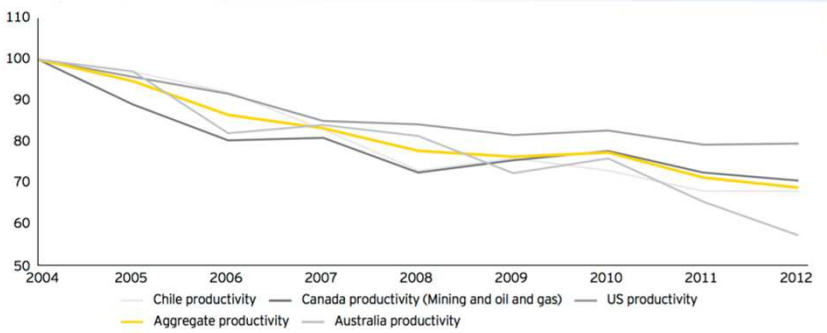
1. What are Secondary mineral resources?
   - by-product in mining
   - by/co-product from reprocessing of waste, tailings and residues
   - by/co-product arising from clean-up of materials
   - by/co-product for environmental management activities, such as environmental remediation
2. Advantages in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

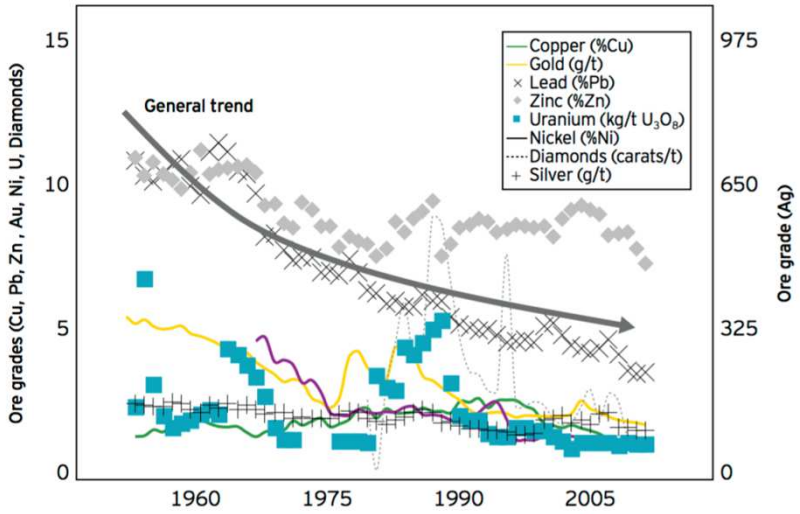
- By product of Copper
  - Bingham Canyon, USA, 1978-89, 2-15 ppm, 50 tU/y
  - Twin Buttes, Arizona, USA, 100 tU/y
  - Yerington, Nevada, USA
- Polymetallic Iron Oxide Breccia Complex
  - Olympic Dam, Australia (Currently, ongoing co-product of Cu and Ag - 3 353 tU/y)
- Carbonatite
  - Phalabora, South 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, Kyrghystan
- 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



Source: Country statistical data, EY



Source: "The Sustainability of Mining in Australia," Department of Civil Engineering, Monash University and the Mineral Policy Institute, April 2009, http://users.monash.edu.au/~gmudd/sustymining.html accessed 23 September 2014.

Change in mindset

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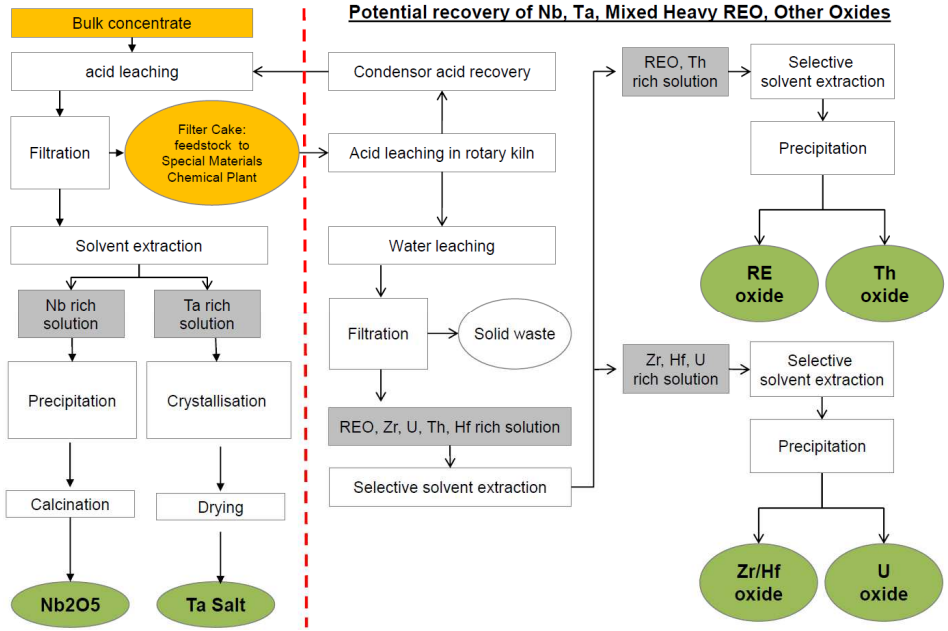
Mostly overlooked Columbite from Pitinga project, Brazil (Mineração Taboca)

Óxidos	Teores (%)	Óxidos	Teores (%)	Óxidos	Teores (%)
Nb_2O_5	29,3	Al_2O_3	1,14	P_2O_5	0,192
PbO	13,5	Y_2O_3	0,939	Gd_2O_3	0,181
SiO_2	10,9	CeO_2	0,811	Sm_2O_3	0,172
Fe_2O_3	9,17	HfO_2	0,746	Pr_6O_{11}	0,143
ZrO_2	6,55	K_2O	0,544	Ho_2O_3	0,130
ThO_2	4,90	TiO_2	0,516	WO_3	0,117
Ta_2O_5	3,81	CaO	0,514	La_2O_3	0,109
U_3O_8	3,16	ZnO	0,445	SrO	0,071
F	2,04	Dy_2O_3	0,331	Cr_2O_3	0,032
SnO_2	1,89	Yb_2O_3	0,315	PF	3,97
MnO	1,64	Er_2O_3	0,312		
Na_2O	1,18	Nd_2O_3	0,215		



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)

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

Future possibilities for U (2/2)

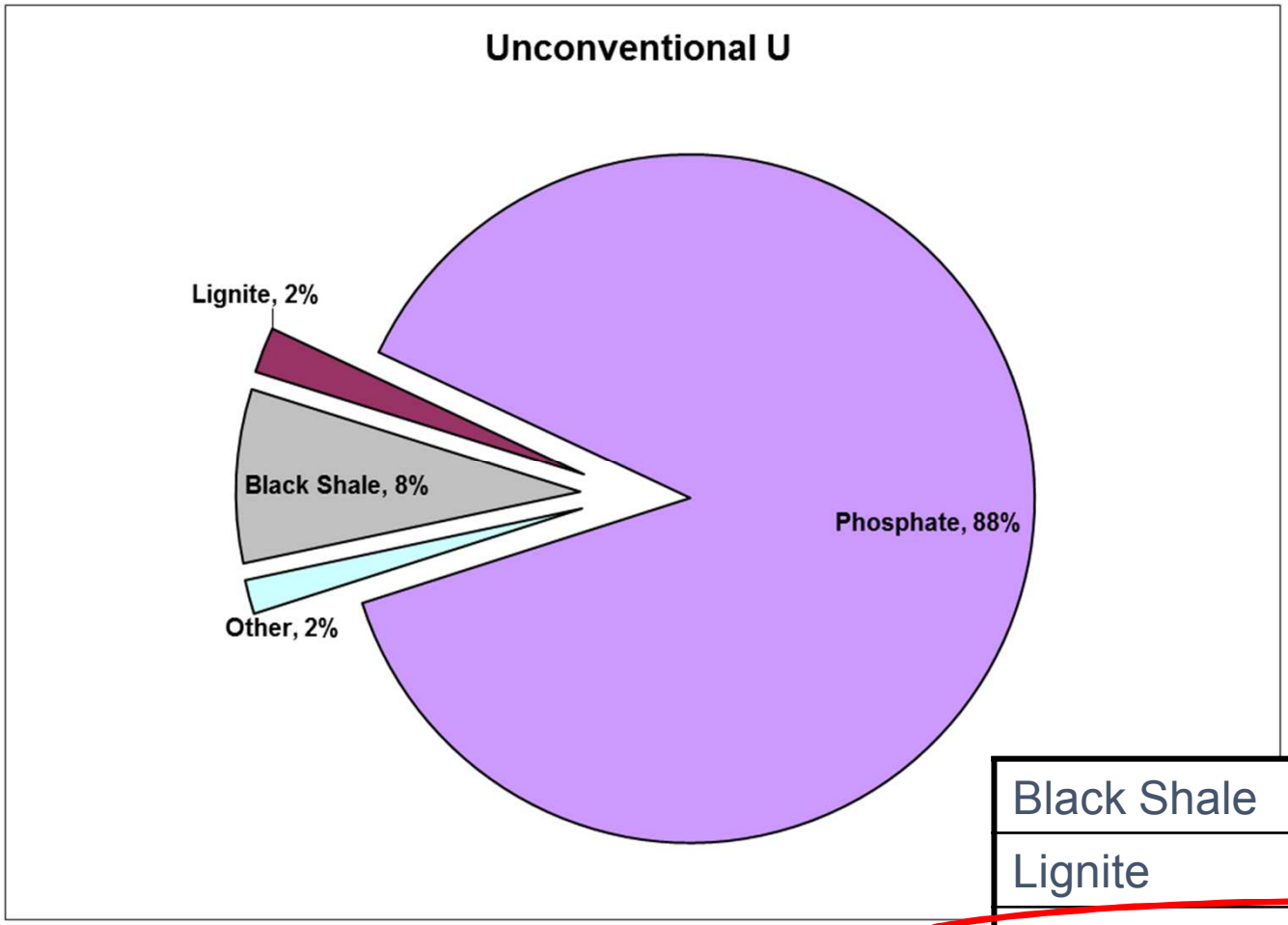
No	Country	Project	Operator	Deposit type	Materials recovered	Nominal production capacity (tU/y)
8	Morocco		OCP	Phosphate	U	1900
9	USA	Plant City	CF	Phosphate	U	2680
10	Brazil	Santa Quitéria	INB – Galvani JV	Metamorphite/Marble hosted Phosphate	P, U, Th	970
11	South Africa	TPM Uranium Project	Harmony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

The Co-product Options

No	Type	Number of reported world deposits	Number of U deposits recorded in UDEPO	Total Resources in UDEPO (t U)	Average Grade (ppm U)	Remarks
1	Intrusive (Carbonatite, Peralkaline, Plutonic, Quartz monzonites)	646 – Porphyry copper deposits [a] 125 – Peralkaline complex [b] 527 – 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		50	20 963 792	17 - 1200	Ni, Co, Cu, U
6	Paleo quartz-pebble conglomerate (Au dominant)		64[j]	1 670 147	30-80	Au, U
	Paleo quartz-pebble conglomerate (U dominant)		25	467 342	30-80	U, REE
7	Heavy mineral sands		77[k]			REE, Ti, Th, Zr, Sn
8	Lignite-coal ash	21 billion tonnes [l]				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 [m]				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

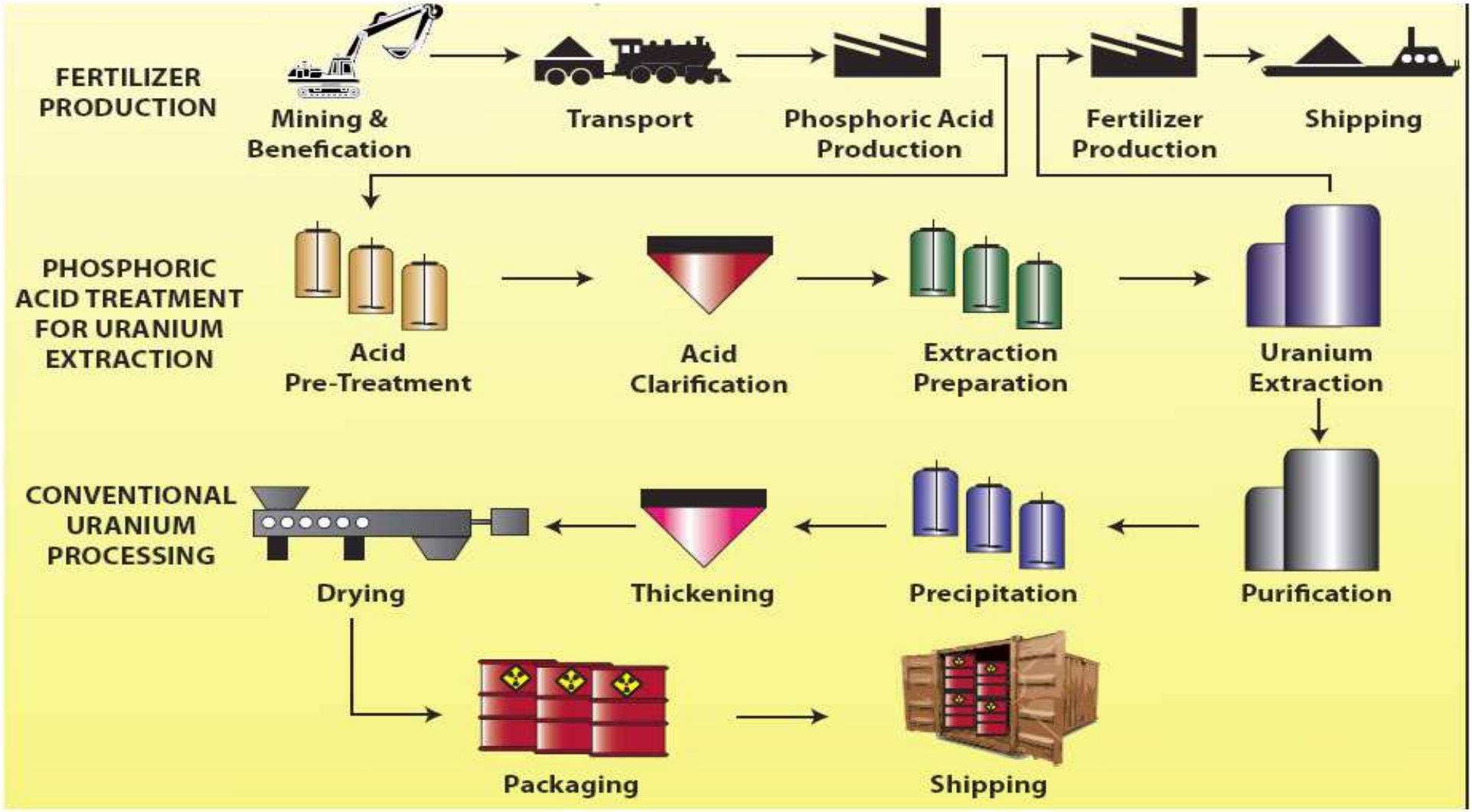
UxP – The Co-product Option



UDEPO, 2012

Black Shale	1,199,086
Lignite	313,685
Phosphates	12,894,830
Other	234,137
Total	**14,641,738**

UxP - U as P co-products for energy and food



Resource Sustainability: the New Equilibrium
Building the bridge to the future from both ends

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Thank you for your kind attention

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