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Smart, sustainable development of phosphate resources: the prospects for phosphogypsum utilization and uranium recovery

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Beneficiation of Phosphates VII

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Julian Hilton,
Chairman,
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The rise of the beneficiators

The new front line

Roots in the 18th century origins of modern science and engineering

"Nature to advantage dressed",
Alexander Pope

Is Green Pristine?

Or making better what we find in nature?

Bene
Fici
Ation

President Xi Jinping: The Silk Road Beneficiator

In his keynote speech at the annual conference of the Boao Forum for Asia, Xi cited a series of proverbs from different nations to accentuate that “people from across the world all have a ready interest in mutually beneficial collaboration”

NEWS

China: Xi Jinping opens Boao Forum

28/03 11:06 CET

Mood music from Mao

During his key note speech, the Chinese president called on the continent to take part in a programme he launched: the so-called ‘Silk Road Economic Belt and the 21st-century Maritime Silk Road Initiatives.’

“The programme and the establishment of the Asian Infrastructure Investment Bank – AIIB – are open to all,” he said. “We welcome the countries along the road and all the Asian nations. We also welcome friends from every continent.”

Britain has announced they’ll sign up for the AIIB, an institution providing financial support to Xi’s programme.

The US, however, has resisted.

"Turnip"
Townsend

The UK 18C Agricultural Revolution

Was based on the science
of soil beneficiation… 4 crop rotation

Holkham Hall: Built on Turnips

Rothamsted Manor: Built on Phosphates

Protect the FEW: Safeguard the Many

FEW: Food Energy and Water Security

For 9 billion people+ …

by 2050

Can we do it?

Should we do it?

Yes, if we get it right

With P, U and REE

And what else?

Have we got the priorities right?

Smarter and Smarter: Homo Faber

Necessary and sufficient…

"Smart 3, 4, 5, 6G" approaches…

"Kiss it better" won't be enough,

but "make it better" might be sufficient…

You are the front line

FEW: Necessary?

U, P, PG… Sufficient?

Is “Green” conservative, or adaptive?

Why in our century do we think natural (green) processes are peaceful?
(The nineteenth century didn’t)


Are mining and beneficiation natural activities?

Context here and now: March 2015

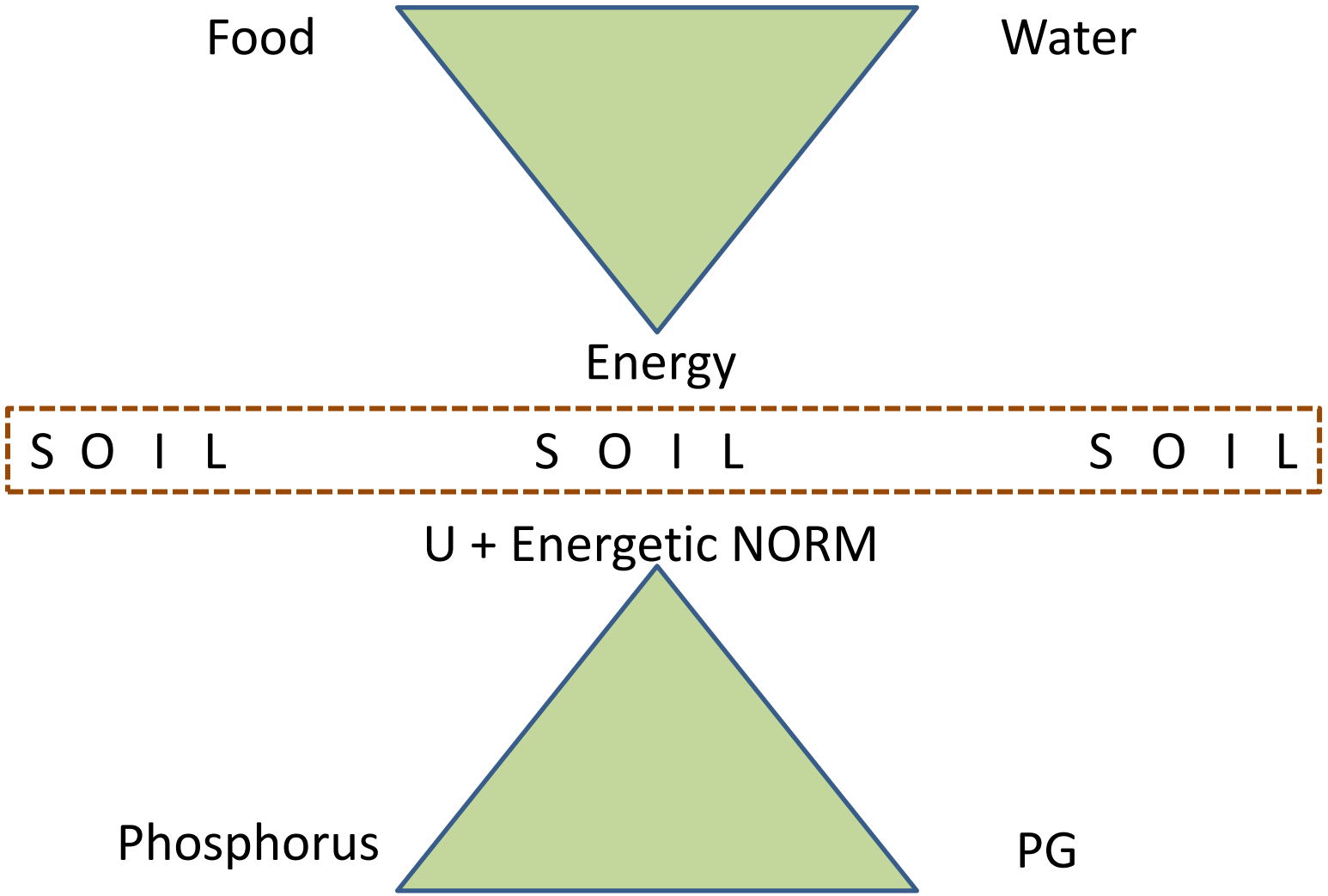
- This is the International Year of the Soil
- The theoretical capacity of the world's soils to feed 9 billion by 2050 is there…
- … but soil fertility and productivity in many parts of the world are either stalled or in decline
- Is an asymptotic gap opening up?
- What can P, PG and U contribute to dealing with it?

Maybe this?
Cotton field in Kazakhstan treated with PG

The answer lies in and under the soil…

- What currently goes in that should go in…
- What currently goes in that (really) should not go in…
- What currently goes in that (ideally) should not go in…
- What currently goes in, but in insufficient quality…
- What currently does not go in that should go in…
- If we disturb the soil, what do we gain, what do we lose?
- What are the options?
- How do we make informed choices (beneficiation)?

Fertile Soil as Fulcrum



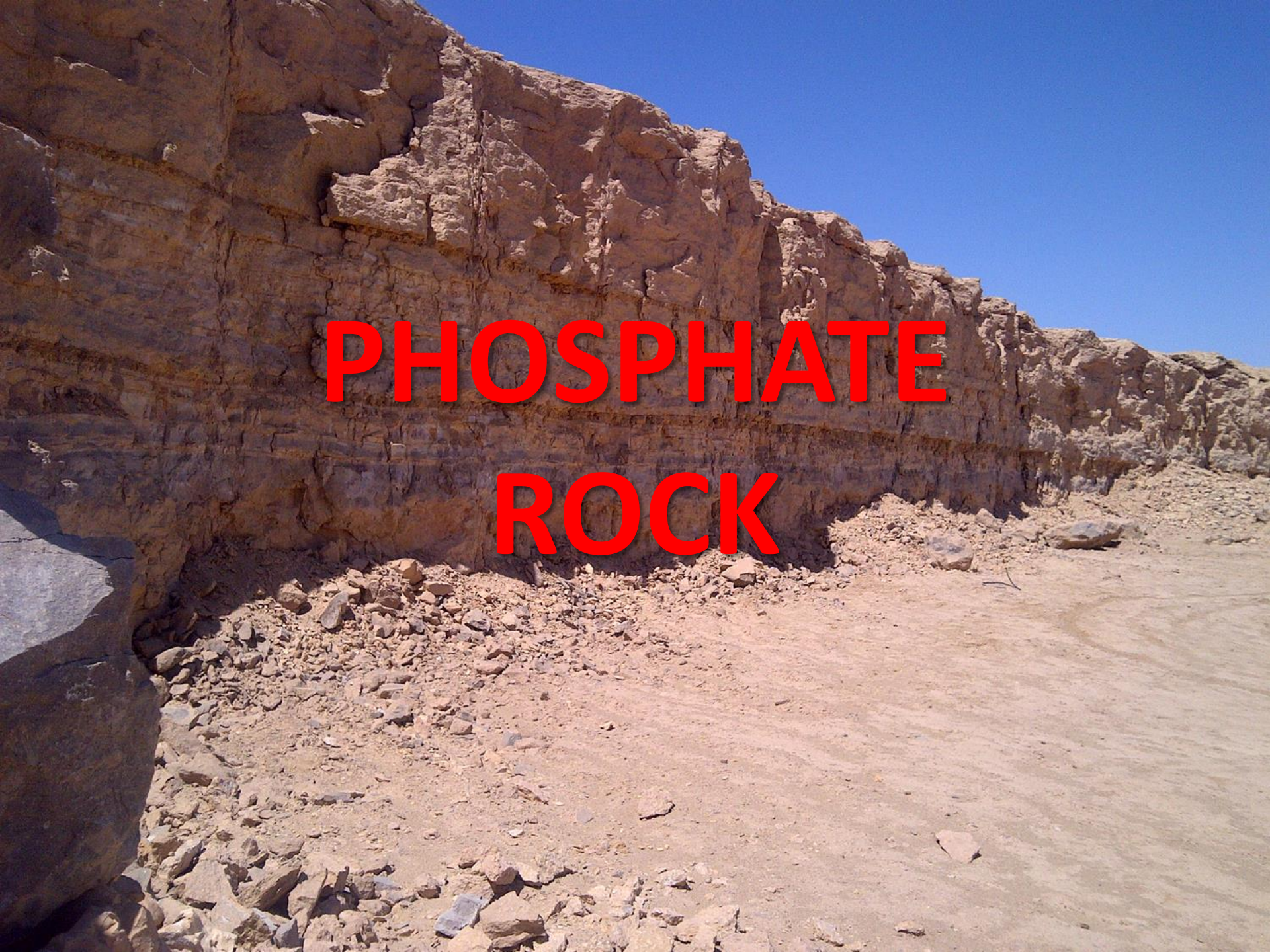
Soil Fertility – the Macro Level

"The ability of a soil to produce the required or optimum level of yield and quality from a given crop, at a given time and under given growing conditions, assuming appropriate, measurable inputs." Johnny Johnston

EU Raw Materials Initiative 2008

In order to address the complex and interrelated challenges of the secure minerals supply chain the European Commission formulated an integrated policy in 2008, the EU Raw Materials Initiative (RMI). The RMI is based on three pillars:

1. Ensuring a level playing field in access to resources in third countries
2. Fostering sustainable supply of raw materials from European sources
3. Boosting resource efficiency and promoting recycling.


PHOSPHATE
ROCK

The EU Critical Mineral List 2014

"Raw materials are fundamental to Europe's economy, and they are essential for maintaining and improving our quality of life."

Antimony	Beryllium	Borates	Chromium	Cobalt	Coking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural Graphite	Niobium
PGMs	Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten	

http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf

What is critical? (1) - Economic

- Economic importance: this analysis is achieved by assessing the proportion of each material associated with industrial megasectors at an EU level. These proportions are then combined with the megasectors' gross value added (GVA) to the EU's GDP. This total is then scaled according to the total EU GDP to define an overall economic importance for a material.

What is critical? (2) - Supply

- Supply risk: in order to measure the supply risk of raw materials, the World Governance Indicator (WGI) was used. This indicator takes a variety of influences into account such as voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law or control of corruption.

Soil is a Critical Material

- Physical condition
- Fertility

Soil Beneficiation:
Sustaining the Critical Equilibrium P Value (CEPV)

1. Define 3 key variables:

- Deficit P = DP
- Sustainable P = SP
- Excess P = EP

From these variables a conceptual "Critical Equilibrium Phosphate Value" (CEPV) can also be determined. The global CEPV derives from the sum of soil/situation-specific equilibrium values, $cepv_1$, $cepv_2$, $cepv_3$, etc.

At the macro level, sustainability is described as the state between a minimum point of biological sustainability and a maximum point of commercial sustainability, with the optimum at or just below the threshold of P excess. This equates to the CEPV.

Pathways to Soil Sustainability

Based on a mixture of factors such as:

- historical (time series) evidence as to sustained (long-term), measurable fertility
- well-grounded hypothesis about likely future soil behaviour
- generic performance or yield ranges that would determine whether a soil qualified as “fertile”

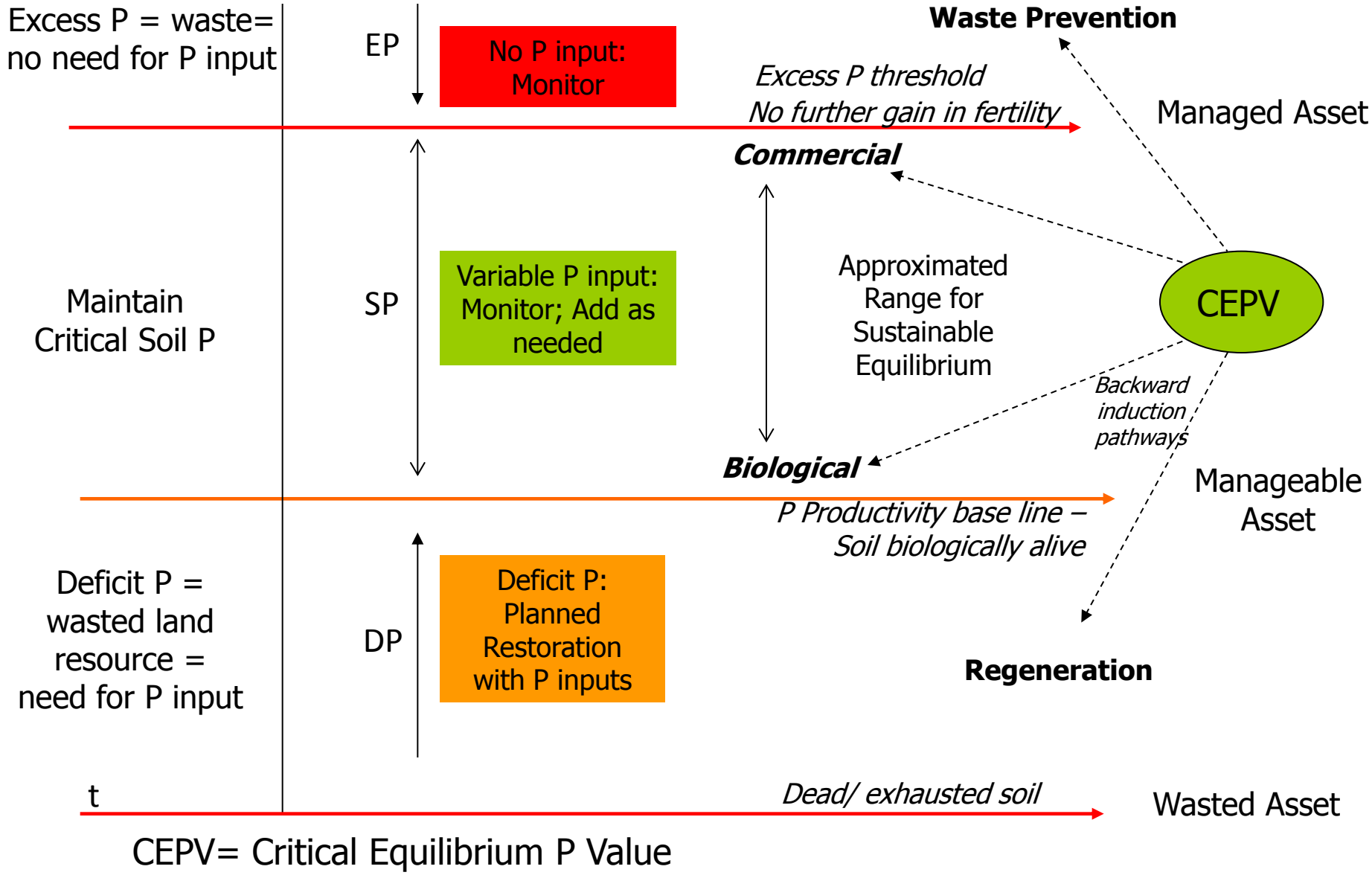
It is possible to approximate what the production requirements for P over time is likely to be, from both primary (mined) and recovered sources (wastes, co-product).

Soil Sustainability in Practice

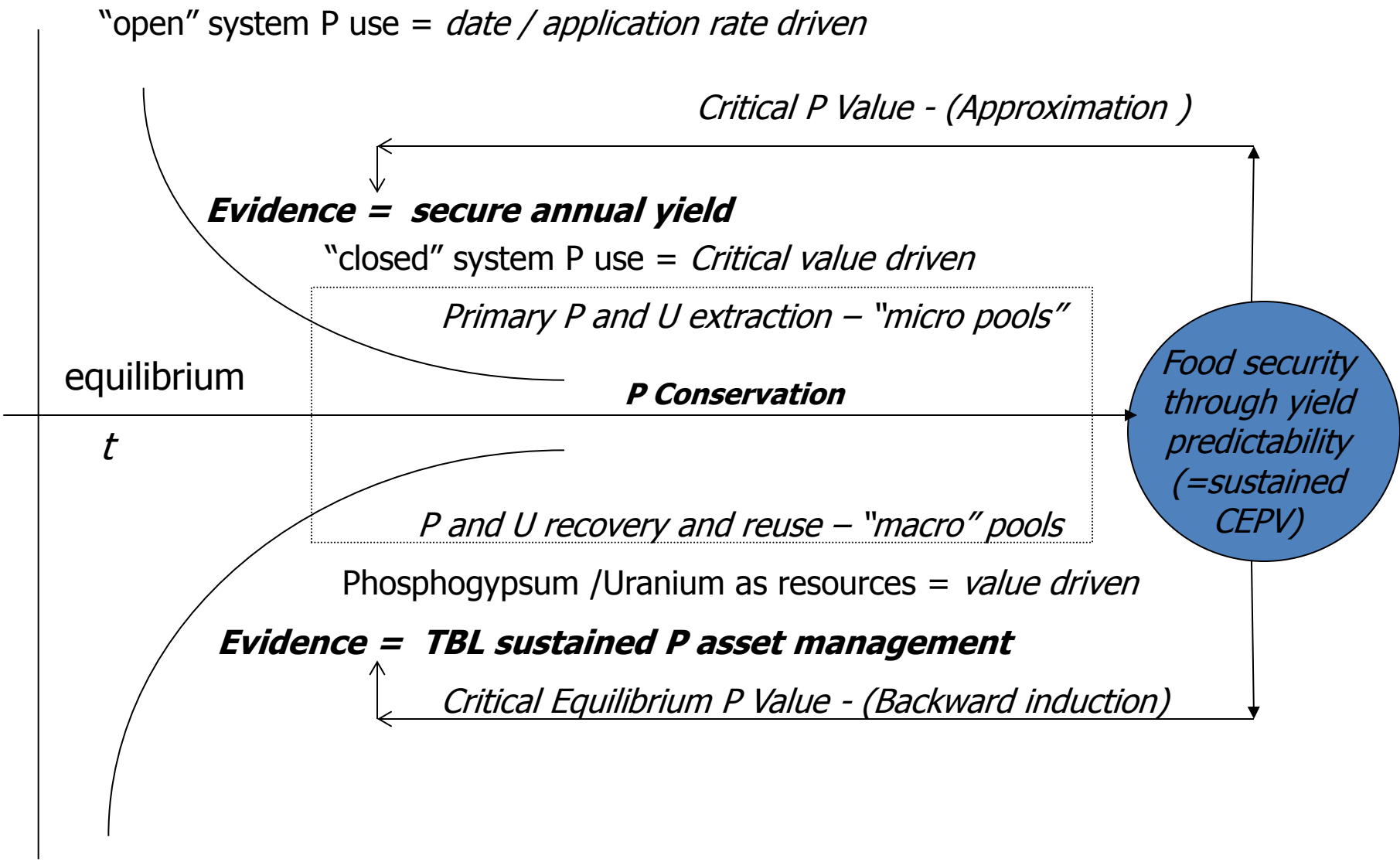
There are four potential “pathways” to sustainability which plot out what inputs are needed and their frequency to reach and then preserve equilibrium:

1. Regeneration
2. Biological fertility threshold
3. Commercial fertility (yield) threshold
4. Waste prevention.

Critical Soil P and the Critical Equilibrium P Value



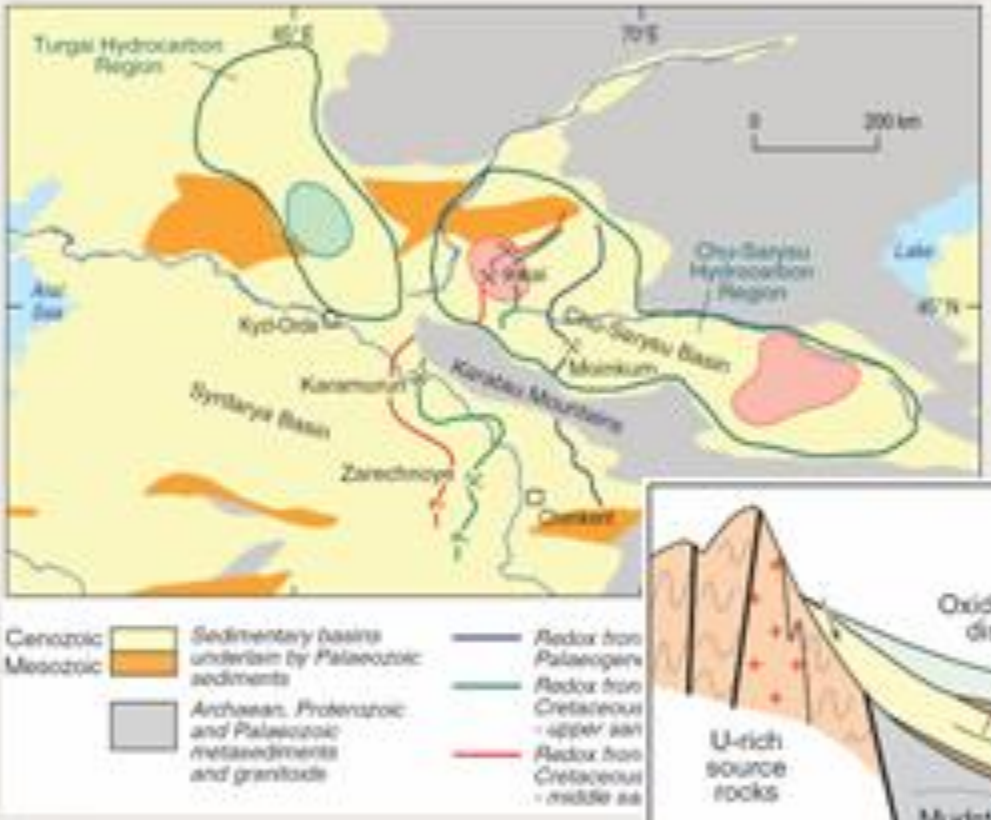
Food Security/ Soil Fertility = Sustained Critical P



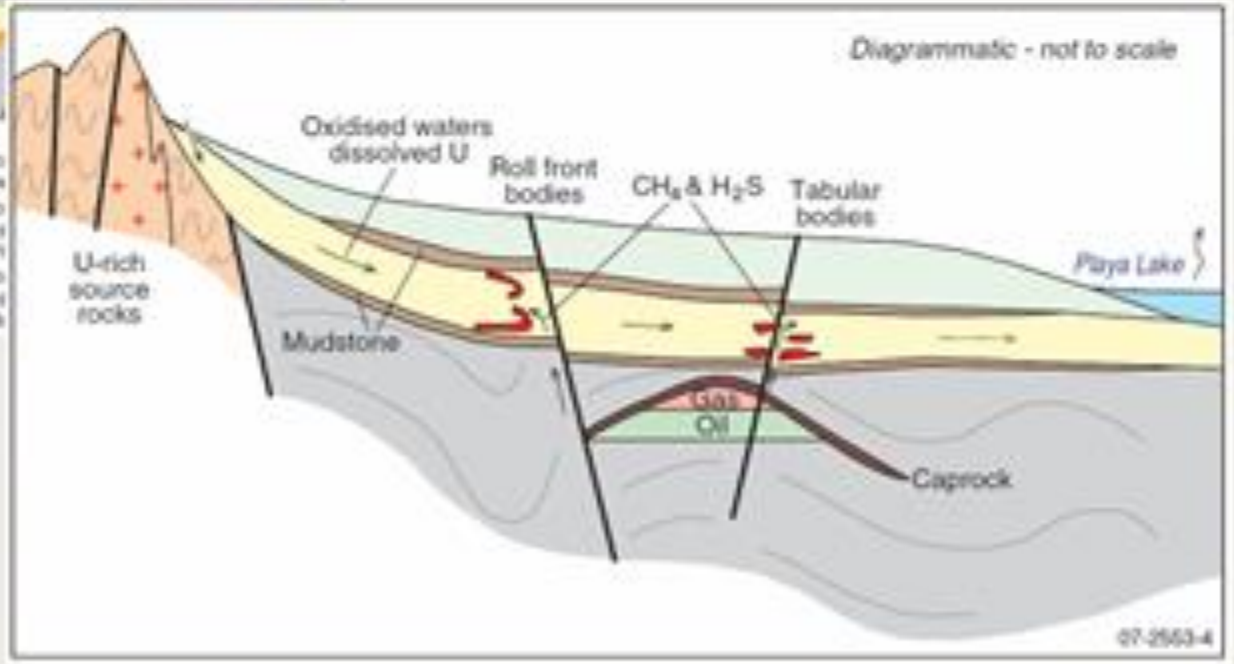
Phosphogypsum as hazardous waste, uranium as *de facto* contaminant = *definition driven*

Kazakhstan – energy basin with U and hydrocarbons

Slide, courtesy Hari Tulsidas, IAEA



- Possible link between oil & gas and uranium, with associated migration of gas along faults, tectonic control of the localisation of roll fronts…



Jaireth et al. 2008

IAEA

Comprehensive Extraction

"Disturb the ground once… extract everything of value in one pass"

- Rethink the flowsheet… rethink the outcome
- Include residues and tailings… zero waste
- Develop new business 3G and 4 G business models
  - Analogous to the Moore's Law, but for resources (oil, gas, minerals)
- Engage with stockholders and stakeholders to achieve "win/win" – the cooperative game theory … leading to significantly enhanced financial return and heightened social acceptance (Social Licence to Operate (SLO))
- Already happening …

See: **New 'Comprehensive' Approaches to Uranium Mining and Extraction**
http://www.iaea.org/OurWork/ST/NE/NEFW/News/2011/repository/New-Comprehensive-Approaches-to-Uranium-Mining-and-Extraction.html

Provenance:
the sedimentary energy basin

- Oil
- Gas
- Coal
- Uranium
- Thorium
- Phosphates
- REEs

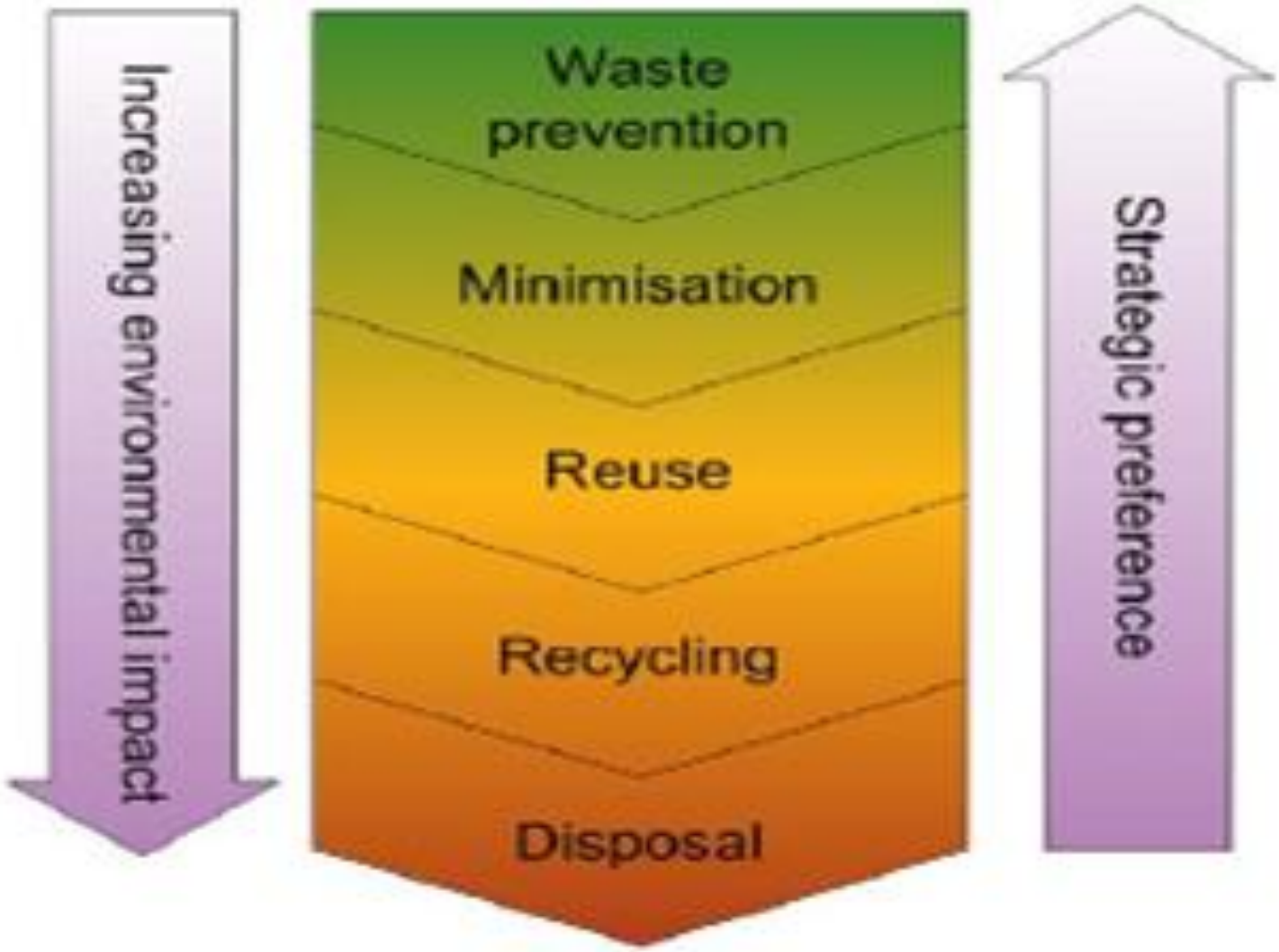
NORM Industries: IAEA

- Uranium mining and processing
- Rare earths extraction
- Thorium extraction & use
- Niobium extraction
- Non-U mining – incl. radon
- Oil and gas
- Production and use of TiO_2
- Phosphate Industry
- Zircon & zirconia
- Metals production (Sn, Cu, Al, Fe, Zn, Pb)
- Burning of coal etc.
- Water treatment – incl. radon.

URANIUM 1 (spot price U $39/lb)

TORONTO, March 26, 2015 /CNW/ - Uranium One Inc. ("Uranium One" or the "Corporation") today reported headline revenues of $260.9 million for full year 2014. Annual attributable revenue(2) was $476.2 million for 2014, including joint venture revenue, based on sales of 10.8 million pounds of produced material(1) at an average realized sales price of produced material of $33 per pound and an average total cash cost per pound sold of produced material(2) of $14. The Corporation's attributable production(3) would have been 12.6 million pounds for 2014 if subsoil rights had not been lost partially during the year

The EU Model


Increasing environmental impact
Waste prevention
Minimisation
Reuse
Recycling
Disposal
Strategic preference

Where to create “smart” value add - Purpose: Process: People

SMARTER BUSINESS MODELS (3G and 4G)

- **Purpose:** Smart policy framework for sustainable, value-add fertiliser production for food and energy security
- **Process:** Increased research and development for smart, efficient fertiliser production and use
- **People:** Training and capacity-building – social capital = smarter work

1. Value Add

- Moving up the value chain
  - Mining → Mining + Processing
- Resource conservation
  - Primary → Primary + secondary
- Sustainability
  - Waste → Zero waste
- Social Capital
  - Physical labour → Smart work

Unconventional (Green?) U Resources

Deposit type/subtype	Resources UDEPO (tU)	Grade (ppm)	IAEA UDEPO deposits	World deposits
Porphyry copper	100 000	10-40	7	691
Peralcaline complexes	393 210	50-250	13	125
Carbonatites	122 342	30-300	11	848
IOCG	2 308 602	30-250	14	> 100
Lignite and coal	7 358 112	1-500	33	1600
Black shale	1 489 147	10-200	44	Several hundred
Phosphates	13 553 900	50-150	50	1635
Total	25 325 313		172	5 - 6000
Sea water	4 500 000 000	3.3 ppb		

Conventional U resources - 7 096 600 tU (The ‘Red Book’ 2011)

U & REE concentration in phosphates

Country	Deposit	U (ppm)
Algeria	Djebel Onk	25
	Djebel Kouif	100
Australia	Duchess	80 - 92
China	Undifferentiated	10 - 39
Egypt	Abu Tartur	40-120
Israel	Arad	150
Jordan	Shidyia	46
Morocco*	Bucraa	70-80
	Khourigba	80-120
Peru	Sechura	47-80
Saudia Arabia	Ma'aden	25-85
Senegal	Taiba	64-70
Syria	Khneifiss	75
Tanzania	Minjingu	390
Togo		77-110
Tunisia		12-88
USA	North Carolina	41-93
	Central Florida	59-200
	North Florida	50-143
	Idaho	60-141

* U in phosphates estimated to be 6.5 million tonnes

Phosphate rock source	Ln_2O_3 (%)
Kola, Russia	0.8-1.0
Florida, USA	0.06-0.29
Algeria	0.13-0.18
Morocco	0.14-0.16
Tunisia	0.14
Quebec, Canada	0.18
Ontario, Canada	1.59% (La_2O_3+Ce_2O_3)
Northern China	1.5 – 6.41 (Total R_2O_3)

- **In the estimated 70 billion tons of phosphate deposits within the Tethys realm, REE concentration averages 300 ppm.**
- **This translates to 2.1 billion tons of REE resources.**
- **It has been experimentally proven that REE also can be extracted along with U using appropriate solvents.**

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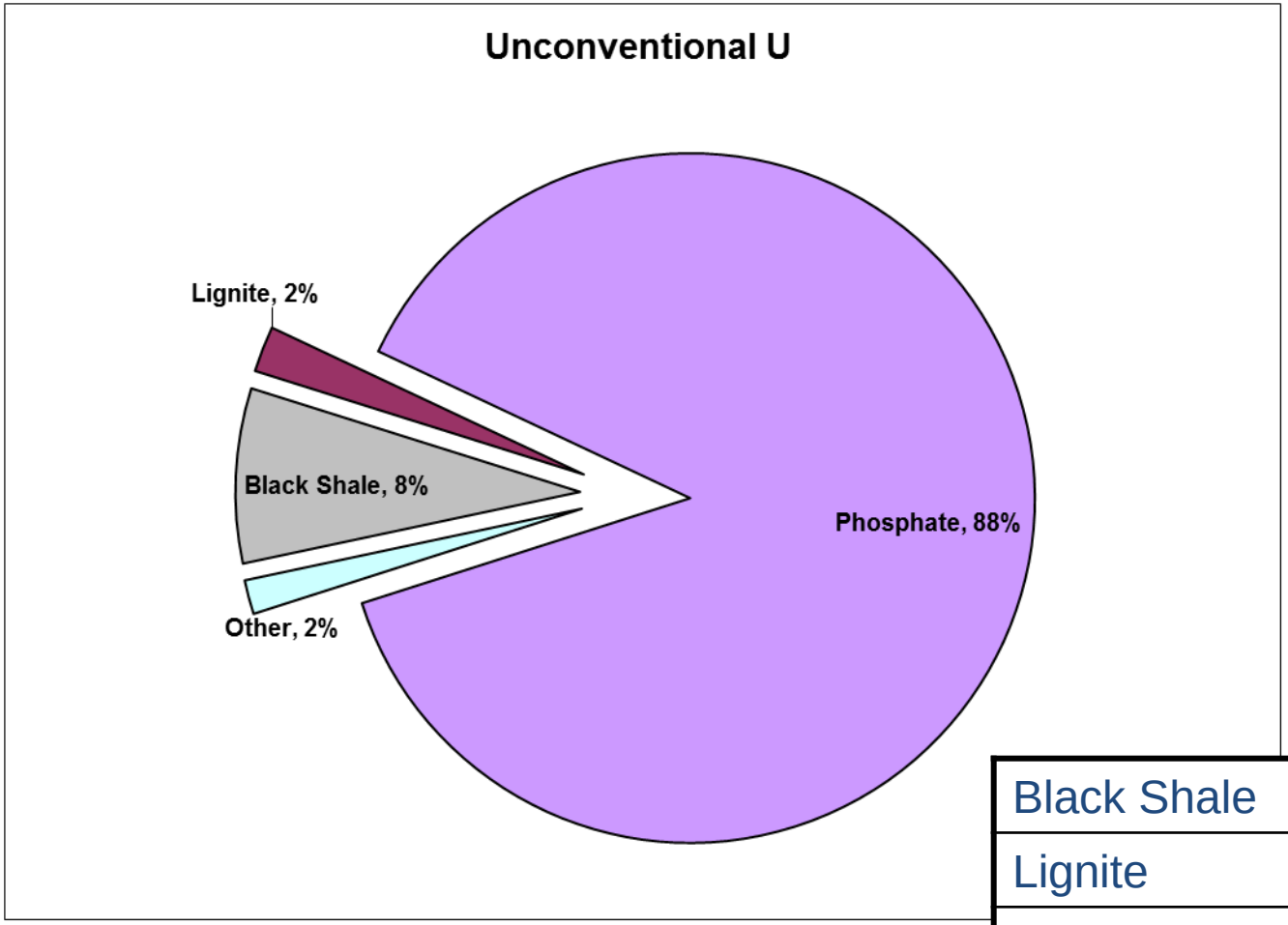
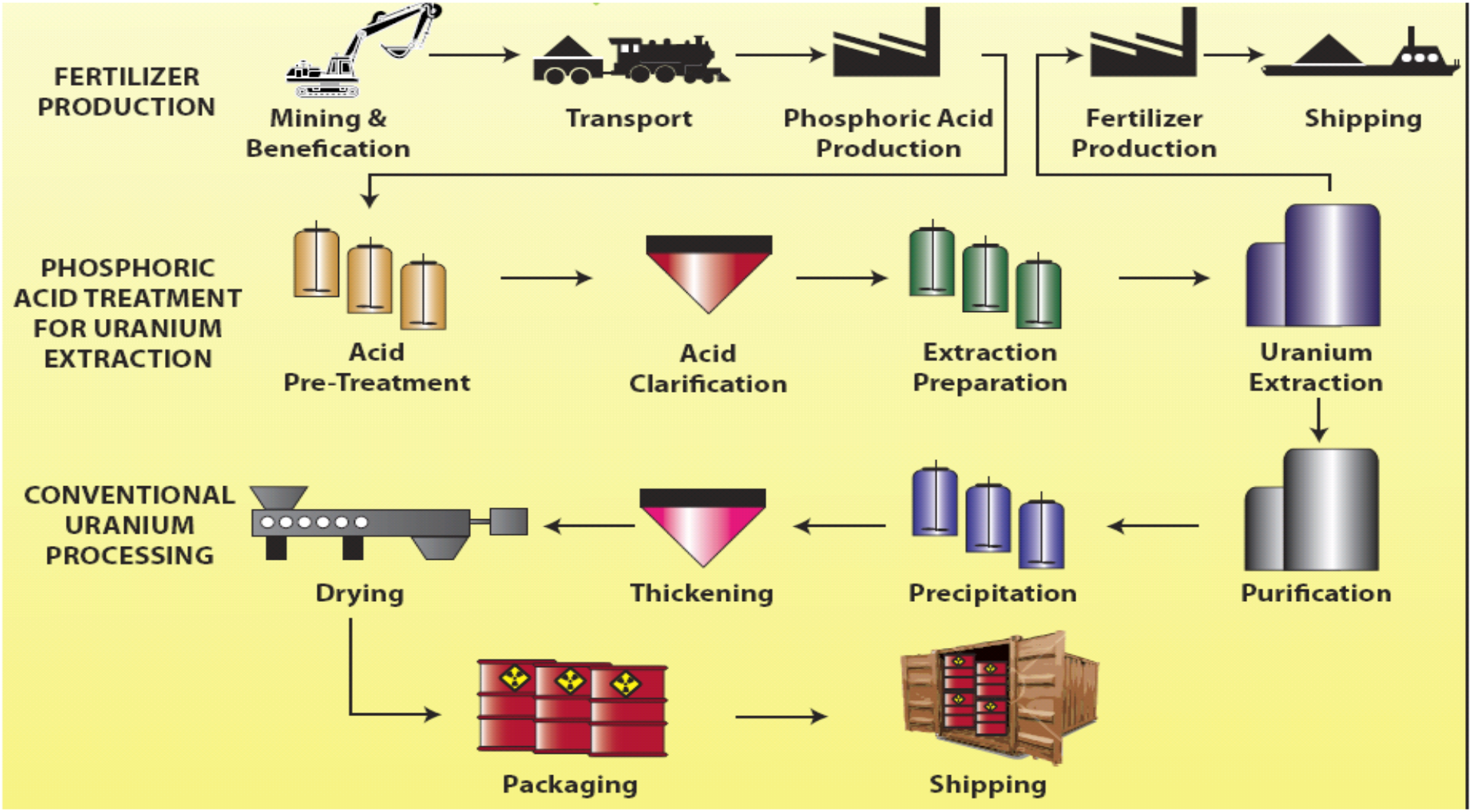
Single Mineral or Complex Resource?



UDEPO, 2012

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

Solvent extraction for U as P by-product




PENNINGTON
(P) Phosphorus
(N)
Nitrogen
18-24-6
(K)
Potassium
15,000
SQ. FT.

3G = Phosphogypsum as Soil Amendment (not Waste)

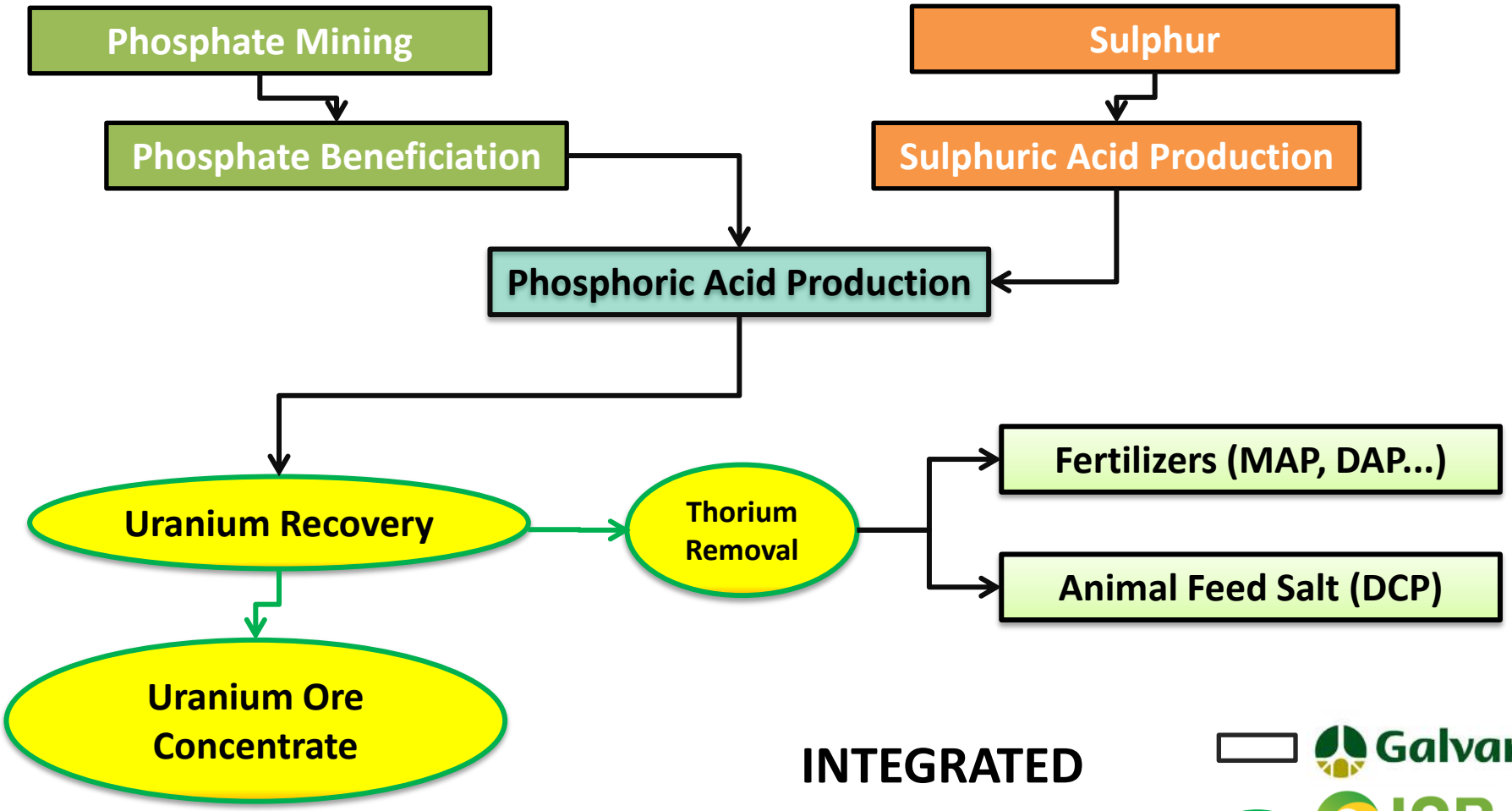
Losses: Estimates of P losses in P lifecycle: Overall efficiency estimated at 5-15% (Hilton, Johnston, Stana, 2010)

Mining	• 100% if P_2O_5 content is below 28.5% (China) • Higher BPL largely mined; Lower BPL values now in play • Shifting boundary between reserve and resource
Mining and beneficiation	• Range: 20-30% (eg Florida) – loss focused on clay
Chemical processing	• Up to 2.5% - undigested rock going to phosphogypsum • Some acid goes to the stack (wet process) • Industry claim is 98%+ total recovery
Agriculture / Food production (inc. fish)	• Erosion • Poor practices, including inappropriate fertilisation, poor crop choice • Need to follow Critical P model
Household waste	• Poor food storage and handling causes significant waste, both of food for consumption and of nutrients (UK WRAP Study, 2009) • Sewage / Wastewater processing – option to recover ~ all P
Waste streams	• Animal manure. • Slaughter (bones and carcasses). • Industry – wide range of products incl detergents, fire retardants etc

Life-cycle management: Nothing goes unnecessarily to waste

	Conventional	Sustainable
Mine (EOL)	Closure and remediation	**Inventorise resources remaining/ future-proof**
Beneficiation	High value ores only	**All ores**
Processing	Stack/ discharge PG	**Use / reprocess PG – agriculture, construction, ammonium sulphate, calcium carbonate**
Resource management	P or K	**P, U, Th, REE, K, Li, I…**

3G Example: Santa Quiteria, Brazil, Combined Uranium and P Project



INTEGRATED FLOWSHEETS

Galvani

INB
INDÚSTRIAS NUCLEARES DO BRASIL

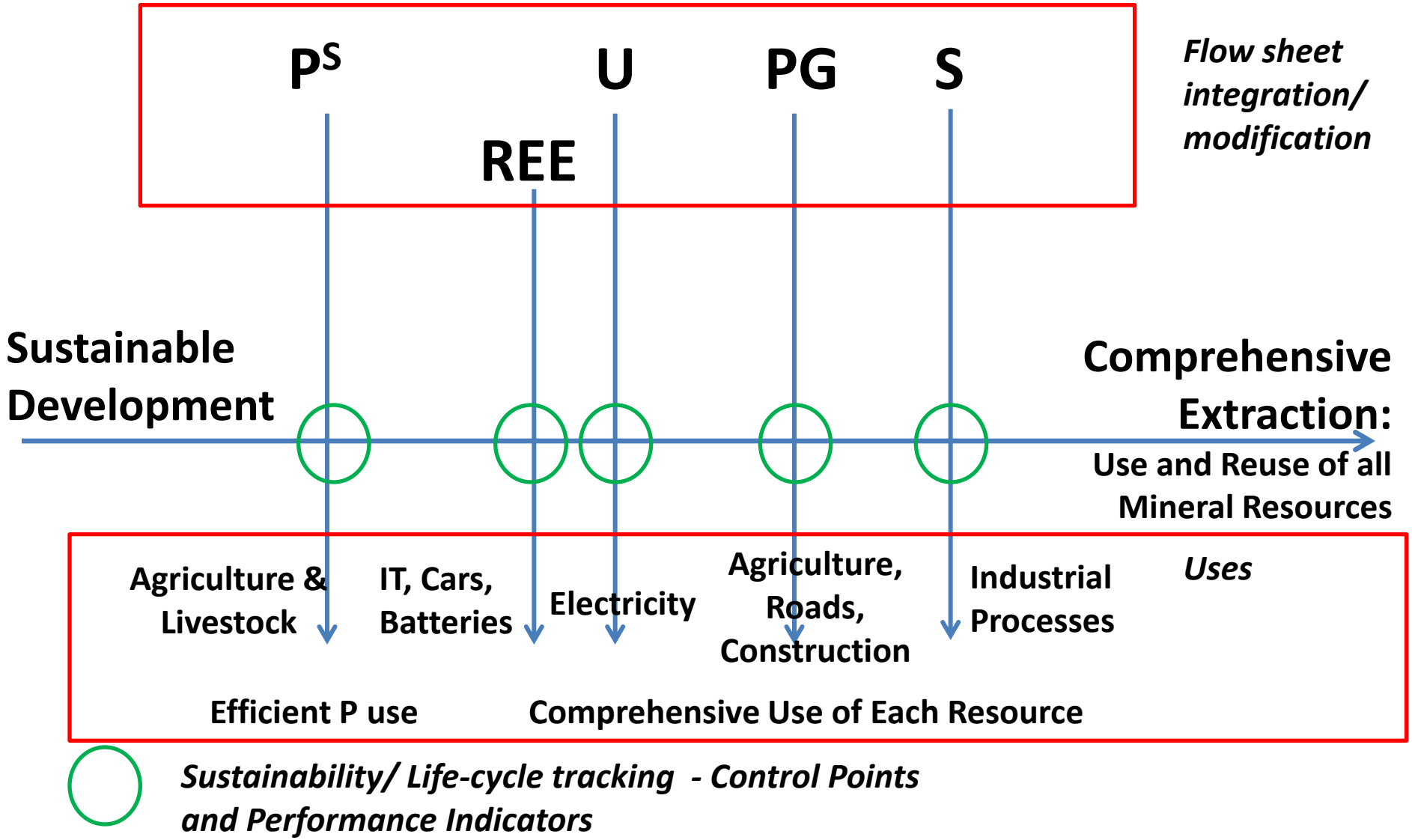
Where to invest?

1. **Smarter thinking:**
2. **Better soils:**
3. **Better practices:**
4. **Better policies:**

- smarter people – training, capacity building, R&D
- reverse a looming global crisis of degraded and saline soils; of sustainable energy
- quantum increase in the efficiency of bringing nutrients (FUE) and water to crops; use soils for the purposes of food
- clear, tight linkages between energy and food security and fertiliser business models

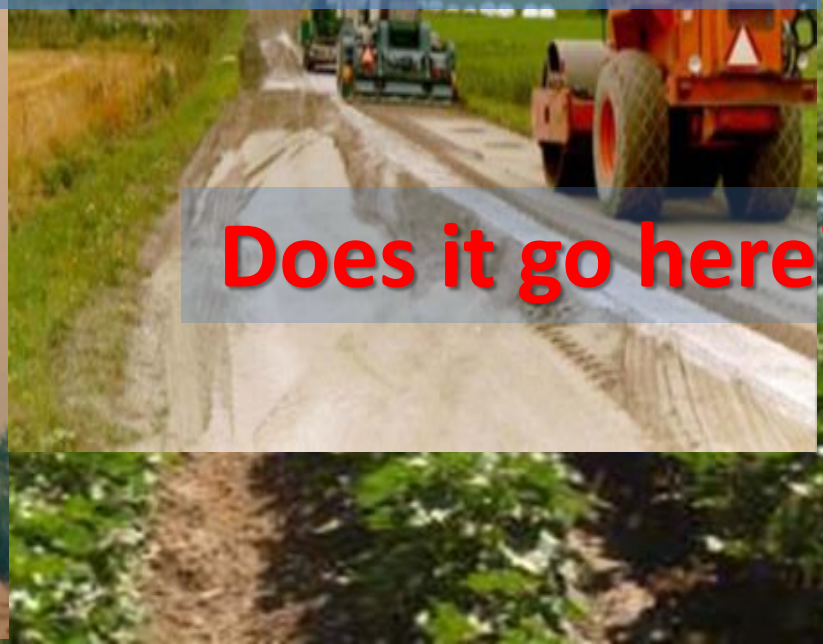
Sustainable uses of P ores (P^S)

Means: integrated flow sheet/ control points/ performance indicators




What story does the picture tell?
Waste or Resource?
What should these rail cars be shipping?
Where should they take it?

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



Fertile Soil as Fulcrum

Food

Water

Energy

S O I L

SO I L

U + Energetic NORM

Phosphorus

PG

Thank you for your beneficent attention

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