STRIVING TOWARD A CIRCULAR ECONOMY FOR PHOSPHORUS:
THE ROLE OF PHOSPHATE ROCK MINING & SUPPLY SECURITY FOR IMPORT-DEPENDENT COUNTRIES

Bernhard Geissler, Gerald Steiner, Ludwig Herman, & Michael Mew

contact: bernhard.geissler@donau-uni.ac.at
# TD LAB FOR SUSTAINABLE MINERAL RESOURCES

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<tr>
<th>Scientific Co-Lead</th>
<th>Co-Leader Practice</th>
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<tr>
<td><strong>Gerald Steiner</strong>  (Danube University / CSH Vienna)</td>
<td><strong>Michael C. Mew</strong>  (CRU International)</td>
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<td><img src="image1" alt="Gerald Steiner" /></td>
<td><img src="image2" alt="Michael C. Mew" /></td>
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<td><strong>Bernhard Geissler</strong>  (Danube University)</td>
<td><strong>Ludwig Hermann</strong>  (ESPP and Proman Consulting)</td>
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<td><img src="image3" alt="Bernhard Geissler" /></td>
<td><img src="image4" alt="Ludwig Hermann" /></td>
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<td><strong>Roland W. Scholz</strong>  (Danube University / formerly ETH Zürich)</td>
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<td><strong>Michael Obersteiner</strong>  (IIASA)</td>
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</tbody>
</table>
# TABLE OF CONTENTS

- **PART 1: The Extended P Supply Chain**
- **PART 2: Supply Security for Importing Countries**
- **PART 3: Circular Economy of P**
- **PART 4: Best Practice Cases**
PART 1: THE EXTENDED P SUPPLY CHAIN
DYNAMIC NATURE OF RESOURCES

EXTENDED PHOSPHORUS SUPPLY CHAIN (EPSC)

**PHASES**

- **PRE-MINING**
  - exploration: drill tests, drill core analysis + further exploration methods of:
    - brownfield areas: on mine sites, close to known depots
    - greenfield areas: unexplored territory, explored territory for another commodity

- **MINING**
  - excavation: open-pit (i.e., surface, open-cast) mining
    - draglines, bulldozers, trucks, pit-cars
    - blasting underground mining
      - conventional room mining
      - continuous mining

- **beneficiation**
  - screening: washing, separation, grinding, further treatment
    - flotation, chemical treatment

- **POST-MINING**
  - processing: wet chemical processing to fertilizer
    (with phosphoric acid as major intermediate product)
  - use: agricultural use
    - fertilizer (MAP, DAP, TSP)
    - animal feed
  - non-agricultural use
    - food additives, industrial use

**ACTIVITIES**

- planning: scheduling, economics, environment, legislative, social

**LOSSES, WASTE + OVERLOOKED OPPORTUNITIES**

- at reserve, resource or geopotential levels (not considerable as losses)
  - touched (above cut-off grade: economic profit + resource loss) & untouched (below cut-off grade: economic profit + resource loss)
  - possibility of stockpiling for later processing (no loss, besides weathering over time)

**INTERMEDIATES**

- rock material below cut-off grade (economic profit + resource loss)
  - zero grade waste (no loss)
  - in solid and effluent forms (e.g., clay)

**EFFICIENCY**

- exploration efficiency
  - URR
  - reserves @ grade
- mining ratio
  - ore @ grade
- beneficiation rate
  - Concentrate @ grade
- secondary recovery rate
  - primarily fertilizers
- use efficiency

**quantities**

- partly known
- known
- mainly unknown
- partly touched
- mainly untouched

**based on Steiner et al. (2015)**
DATA RELATED ISSUES

Long term PR production series, by data source

Recent PR production by data source

Geissler et al. (2018a)
PART 2: SUPPLY SECURITY FOR IMPORTING COUNTRIES
PR MARKETS – A GLOBAL PICTURE

Global PR production in 2015

PR deposits by type of origin

Geissler et al. (2018)

Van Kauwenbergh et al. (2013)

Geissler et al. 2019
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GLOBAL DEVELOPMENTS

Geissler et al. 2019

Steiner and Geissler (2016)
CURRENT RESERVE SITUATION

Global phosphate rock reserve-to-production and reserve base-to-production ratios

Country-based phosphate rock reserve-to-production and reserve base-to-production ratios

Geissler et al. (2019b) compiled from USGS data

Geissler et al. 2019
MARKET CONCENTRATIONS 1/3

HHI developments of reserves and reserve-base

Geissler et al. (2019b)
MARKET CONCENTRATIONS 2/3

Geissler et al. (2019b)

Global PR volumes and corresponding HHIs based on BGS/ITC data

- Total Production
- HHI Production
- Total Imports
- HHI Imports
- Total Exports
- HHI Exports

Geissler et al. 2019

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MARKET CONCENTRATIONS 3/3

- **Global PA volumes and corresponding HHIs based on Fertecon/CRU data**
  - Total Production
  - Total Imports
  - Total Exports
  - HHI Production
  - HHI Imports
  - HHI Exports

- **Global DAP volumes and corresponding HHIs (country-based) on Fertecon/CRU data**
  - Total Production DAP
  - Total Imports DAP
  - Total Exports DAP
  - HHI Production DAP
  - HHI Imports DAP
  - HHI Exports DAP

Geissler et al. (2019b)
PART 3: CIRCULAR ECONOMY OF P
MACRO PERSPECTIVE: PHOSPHATE ROCK MINING – INNOVATION – NEXUS

Social
inter- and intragenerational fairness

Improving P2O5 recovery

Sustainable innovation

Waste utilization

Recovery of by-products

Ecological
within global boundaries

Economic
shareholder responsibility

Geissler et al. (2019b)
MICRO PERSPECTIVE: COST STRUCTURE BREAKDOWN 1/2

Global comparison

Weighted average: Igneous vs. Sedimentary

Geissler et al. (2019a) based on CRU data

STRIVING TOWARD A CIRCULAR ECONOMY FOR PHOSPHORUS
MICRO PERSPECTIVE: COST STRUCTURE BREAKDOWN 2/2

Geissler et al. (2019a) based on CRU data
STRIVING TOWARD A CIRCULAR ECONOMY FOR PHOSPHORUS

TOWARD A CIRCULAR ECONOMY

- exploration
- excavation
- beneficiation
- processing
- use
- recycling
- waste utilization of high-volume by-products (e.g., phosphogypsum)
- processing losses
- tailings
- overburden & material
- recovery of by-products e.g.,
  - uranium
  - rare earth elements
- overlooked opportunities
- sustainable mine planning strategies

Agricultural Phosphorus Use Circle

improvement of $\text{P}_2\text{O}_5$ recovery
- tailings, overburden, clay, etc.
- (improved) flotation processes
- ...

losses from recovery

policy on recycled fertilizer

Geissler et al. (2018b)

Geissler et al. 2019
PART 4: BEST PRACTICE CASES
JDC’S IMPROVED HARD PROCESS (IHP)

- Low Grade Phosphate Rock
- Petroleum Coke
- Silica Sand

Flowchart showing the process:
1. Drying
2. Grinding
3. Agglomeration
4. Induration Grate-Kiln
5. Ported Kiln
6. Hydrator

Yields:
- J-Rox Commercial Aggregate
- High-Grade Phosphoric Acid

Blake (2017)
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- Wellmer, F.-W., Scholz, R.W., 2017a. Putting Phosphorus First: The Need to Know and Right to Know Call for a Revised Hierarchy of Natural Resources. Resources 6, 20.