Evaluation of Anthropogenic Resource Stocks and Flows: The case of Phosphorus and Zinc

Jakob Lederer and Johann Fellner
Christian Doppler Laboratory for Anthropogenic Resources

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I. Background

II. Case study Phosphorus stocks in Austria

III. Case study Zinc recovery from waste incineration residues in Europe
Anthropogenic resources

Resources

Natural resources
  - Natural stock resources
  - Natural flow resources

Anthropogenic resources
  - Anthropogenic stock resources
  - Anthropogenic flow resources

P-stocks
Zn-flows
Anthropogenic and natural stocks

Million tons

anthropogenic stock  reserve base

Evaluation of natural resources: McKelvey

Increasing geological certainty (e.g. drillings, geophysical techniques...)

<table>
<thead>
<tr>
<th>Cumulative Production</th>
<th>IDENTIFIED RESOURCES</th>
<th>UNDISCOVERED RESOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demonstrated</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td>Indicated</td>
</tr>
<tr>
<td></td>
<td>Probability</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>Hypothetical (q)</td>
<td>Speculative</td>
</tr>
</tbody>
</table>

- **ECONOMIC**
  - Reserves
  - Inferred Reserves
  - Marginal Reserves
- **MARGINALLY ECONOMIC**
  - Marginal Reserves
- **SUBECONOMIC**
  - Demonstrated Subeconomic Resources
  - Inferred Subeconomic Resources

## Evaluation procedure anthropogenic resources

<table>
<thead>
<tr>
<th>Evaluation step</th>
<th>Method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Prospetion</td>
<td>Identification of stocks based on macro-level MFA</td>
<td>Relevant anthropogenic stocks identified and estimated</td>
</tr>
<tr>
<td>2. Exploration</td>
<td>Detailed stock characterization based on micro-level studies</td>
<td>Grade, size of stock, uncertainties</td>
</tr>
<tr>
<td>3. Evaluation</td>
<td>Selection of technologies and economic analysis of costs &amp; revenues</td>
<td>Cost/revenue ratio</td>
</tr>
<tr>
<td>4. Classification</td>
<td>McKelvey cross classification</td>
<td>Reserves, resources, and other occurrences of anthropogenic stocks</td>
</tr>
</tbody>
</table>

Case study I:  
Resource evaluation of anthropogenic phosphorus stocks in Austria

1. Identification of stocks

2. Tonnage & grade + uncertainty

3a. Production costs projection (to produce P-fertilizer)

3b. P-fertilizer price projection

4. Classification

## Anthropogenic P-stocks & mining concepts

<table>
<thead>
<tr>
<th>No</th>
<th>Stock name</th>
<th>Stock size</th>
<th>Δ Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Animal husbandry</td>
<td>7,000</td>
<td>- 33</td>
</tr>
<tr>
<td>2</td>
<td>Agricultural soil</td>
<td>12,000,000</td>
<td>+ 5,500</td>
</tr>
<tr>
<td>3</td>
<td>Other soils and forest</td>
<td>6,300,000</td>
<td>- 500</td>
</tr>
<tr>
<td>4</td>
<td>Household &amp; infrastructure</td>
<td>125,000</td>
<td>+2,500</td>
</tr>
<tr>
<td>5</td>
<td>Waste management (including waste residues in building materials)</td>
<td>not determined</td>
<td>+ 8,700</td>
</tr>
<tr>
<td>6</td>
<td>Water bodies</td>
<td>6,000</td>
<td>+ 1,300</td>
</tr>
</tbody>
</table>

Anthropogenic P-stocks in waste management

1. Landfills incineration residues
   - Mixed ash landfill: fly ashes and bottom ashes of different origin
   - MSW bottom ash landfill

2. Landfills
   - MSS landfill I+II: sewage sludge landfills
   - MSW landfill I+II: MSW landfills

3. Building materials
   - Ashes and P-rich wastes in cement production
   - Slags from steel production (LD)
McKelvey diagram for anthropogenic P-stocks in Austria in t

<table>
<thead>
<tr>
<th></th>
<th>Identified resources</th>
<th>Potentially undiscovered resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demonstrated</td>
<td>Inferred</td>
</tr>
<tr>
<td>Economic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marginally economic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subecononic</td>
<td>70,000</td>
<td>32,000</td>
</tr>
<tr>
<td>Low-grade materials</td>
<td>89,000</td>
<td>105,000</td>
</tr>
<tr>
<td>Not extractable</td>
<td>720,000</td>
<td>374,000</td>
</tr>
<tr>
<td>Total</td>
<td>1,020,000</td>
<td>511,000</td>
</tr>
</tbody>
</table>
Anthropogenic P-stocks in Austria

Size of stock in 1,000 t of P

- Mixed ash landfill
- MSW bottom ash landfills
- MSS landfills I
- MSS landfills II
- MSW-landfills I
- MSW-landfills II
- Steel- and iron slag
- Building materials
- Water bodies
- Households & infrastructure
- Soils

Increasing extraction costs:
- Subeconmic
- Low-grade materials
- Not extractable
Anthropogenic P-stocks Austria: Conclusions

- **Results**
  - Evaluation sufficient to show that the bulk of the stock is not recoverable
  - Material flow management (e.g. not mixing ashes of different P-grade)

- **Further research**
  - Classification of deposits within one group
  - Assessment of production technology
  - Environmental considerations
Resource evaluation of Zinc flows in residues of European waste incinerators

Why Zinc from waste incineration fly ashes?

**Economic value of heavy metals (in €/t fly ash)**

- Ag, € 1.7
- Ni, € 0.9
- Cu, € 6.1
- Cd, € 0.4
- Mo, € 0.5
- Sn, € 11.7
- Pb, € 7.9
- Sb, € 6.2
- Fe, € 3.7
- Zn, € 30.8

Based on average fly ash composition of Viennase waste incinerators

**Established technology**

1. Acidic extraction
2. Solidification
3. Solvent extraction + electrolysis
4. Neutralisation & waste water treatment

Washed fly ash → non-hazardous waste landfill

FLUREC
Methods

1. Exploring Zn flows
   - Waste quantities incinerated
   - Combustion technologies & air pollution control installed
   - *Amount of fly ashes and Zn contents*

      → **MFA for Zn flows**

2. Evaluation of Zn flows
   - Material & energy balance for FLUREC
   - Economic valuation
   - Monte Carlo Simulation

      → **Spec. production costs for Zn**

3. Classification of Zn flows
1. Exploring Zn flows

Mass flows of Zn (in 1,000 Tons)

Import: 78±1.6 Tg/a
MSW + IW

Import: 69±8.7 Gg/a

Flows of Zinc [Gg/a]

MSW + IW

Waste incineration, EU-28 + Switzerland & Norway, 2011
2. Economic evaluation of Zn flows

Costs/revenues refer to 1 ton fly ash

- electricity
- means of production (e.g. HCl, NaOH)
- resin material (Hg adsorber)
- non-hazardous waste landfilling
- investment
- secondary Zn (net production of Zn)
- revenues concentrate + savings quicklime
- Disposal of untreated fly ash (hazardous waste)
3. Classification of Zn flows

- **Economic**
  - Market price for Zn (€ 1.6/kg Zn)
  - Bottom ash & FBC fly ash

- **Marginal economic**
  - 1.5 times market price for Zn
  - Dry & semidry APC

- **Subeconomic**
  - 10 times market price for Zn
  - Wet APC (boiler & filter ash)

- **Other occurrences**
  - 90% quantile
  - Mean value
  - 10% quantile

Specific production costs of Zn [€/kg Zn]
McKelvey diagram for Zn flows in European waste incineration residues (in t/a)

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<th>Identified resources</th>
<th>Potentially undiscovered resources</th>
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<tr>
<td></td>
<td>Demonstrated</td>
<td>Inferred</td>
</tr>
<tr>
<td>Economic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marginally economic</td>
<td>4,100</td>
<td>700</td>
</tr>
<tr>
<td>Subeconimic</td>
<td>7,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Low-grade materials</td>
<td>47,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Total</td>
<td>69,000</td>
<td>9,000</td>
</tr>
</tbody>
</table>
Zn in European waste incineration residues

- Bulk of Zn flows not recoverable
- Significant uncertainties with respect to economic evaluation
- Major driver – alternative disposal costs for fly ash
- Preferable
  - Grate furnace & wet APC & separate collection of filter ash
Conclusions and outlook

- Evaluating stock and flow resources with similar approaches
- How about dealing with stocks in use (e.g. buildings)?
- Detailed evaluation of extraction technologies
- Building-up data bases for anthropogenic resources
Thank you for your attention!