Phosphorus recovery in Europe
Results from the European P-REX project
Background and Outlook

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State of the art of technical phosphorus recovery in Europe
Background
Phosphorus: feeding the world

FERTILIZERS
139 Mt rock
(70% to phosphoric acid production)

ANIMAL NUTRITION
11.4 Mt rock

INDUSTRY
10.5 Mt rock
30% Others
59% Detergent
11% Food

www.aguiaresources.com.au

University of Applied Sciences and Arts Northwestern Switzerland

www.p-rex.eu
Demand Pressures

World Population Growth

- Developing regions
- Industrialized regions

Grown for Biofuel
Geopolitical risk and price instability

Prices: World bank 2016
EU could improve mineral P supply security through recovery

Conventional (organic) recycling today
147 kt in sewage sludge and 1700 kt in manure recycled

Sources: P-REX policy brief
Van Dijk et al “Phosphorus flows and balances of the European Union Member States

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EU reacted on the phosphorus price spike in 2008.
State of the art of technical phosphorus recovery in Europe
Overview P-REX

- FP7 European Research and demonstration project
- Period: 2012-2015
- 15 Partner from 8 countries
- 4.4 million € (EU: 2.9 million €)

Overall Objective: EU-wide implementation of phosphorus recovery and recycling from wastewater considering regional conditions
### The assessed processes

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Process name</th>
<th>Data quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge Precipitation</td>
<td>Airprex™</td>
<td>Commercial production</td>
</tr>
<tr>
<td>Liquor precipitation 1</td>
<td>Pearl®</td>
<td>Commercial production</td>
</tr>
<tr>
<td>Liquor precipitation 2</td>
<td>Struvia™</td>
<td>Pilot</td>
</tr>
<tr>
<td>Sludge leaching 1</td>
<td>Gifhorn</td>
<td>Test production</td>
</tr>
<tr>
<td>Sludge leaching 2</td>
<td>Stuttgart</td>
<td>Pilot</td>
</tr>
<tr>
<td>Sludge metallurgic</td>
<td>Mephrec®</td>
<td>Pilot</td>
</tr>
<tr>
<td>Ash leaching 1</td>
<td>LeachPhos</td>
<td>Test production</td>
</tr>
<tr>
<td>Ash leaching 2</td>
<td>Ecophos</td>
<td>Commercial P rock. Pilot ash. No technical assessment in P-REX.</td>
</tr>
<tr>
<td>Ash thermo-chemical</td>
<td>Ashdec</td>
<td>Test production</td>
</tr>
</tbody>
</table>

*Partial data on Budenheim, Crystalactor, Nuresys*
AirPrex process

Sludge precipitation

precipitation reactor, several full scale plants

product

[CNP, BWB]
Ostara/Pearl Process

Liquor precipitation

Several full-scale plants in operation

Product

[Seymour, 2009]
Liquor precipitation

Struvia Process

- Digested Sewage Sludge
  - Polymer
  - Decanter
  - Dewatered Sludge
  - Lamella settler
    - MgCl₂
    - NaOH
    - Sludge Liquor
    - MAP Sludge
    - Liquor
    - Struvite

Process demonstrated within P-REX in pilot scale (1’000 L/h)
Demonstration plant scale: 50'000 p.e.

Gifhorn process

Sludge leaching
Stuttgart process

Sludge leaching

Solution Reactor

H₂SO₄ → Solution Reactor

Decanter

Precipitation Reactor

MgO
Citric Acid
NaOH

Sedimentation Tank

MAP

Pilot plant scale: 8’000 p.e.

Product

[Mohn, 2013]
Leachphos

Ash leaching

Pilot study 2012-13 by BSH
40 t ash

Pilot plant in P-REX
50 kg of dry ash per batch
ASH DEC

Ash thermal treatment

Pilot plant 2008-2010
1500 t ash (MgCl₂-additive)

Pilot study 2014 in P-REX
4 t ash (Na₂SO₄-additive)
Mephrec

Sludge metallurgical treatment

Pre-Pilot trial 2008
1.5 t briquettes

Pilot plant 07/2016 to 10/2017, Nürnberg, Germany:
0.5 t/h briquette
1000 h operation time
6.7 M€
Summary technologies

- Mineral outputs
- Purification, concentration and/or increase in plant availability
- Product grade
  - 20%-30% P$_2$O$_5$ on DM in struvite from sludge and sludge liquor
  - Lower for metallurgic and thermochemical treatment. Higher for ash leaching
- Process yield (% of P in sludge)
  - ~10% precipitation
  - ~50% sludge leaching
  - 70-100% dry sludge or ash based
Recovering Materials are often only sparingly water soluble

- Fertilizer potential using
  - Solubility in neutral ammonium citrate
  - Pot trials for «relative agronomic efficiency» (RFE) compared to Triplesuperphosphate (TSP)
Pot trials

- 7 recovered materials
- References: ash, sludge Chem-P and EBPR, TSP
- Two years with one P application for short and longer term availability
- Two soils different in pH-value
- Maize plant height and mass development
- Exact tests: nutrient adjustments and replications
## Results fertilizer potential

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>RFE Y1 (average pH 5&amp;7)</th>
<th>RFE Y2 (average pH 5&amp;7)</th>
<th>Solubility in NAC+ H2O</th>
<th>RFE,Y1, RFE,Y2 and NAC ≥80%?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge precipitation 1</td>
<td>Struvite</td>
<td>110</td>
<td>91</td>
<td>94</td>
<td>YES</td>
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<tr>
<td>Liquor precipitation 1</td>
<td>Struvite</td>
<td>72</td>
<td>90</td>
<td>94</td>
<td>NO*</td>
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<tr>
<td>Sludge leaching 2</td>
<td>Struvite</td>
<td>95</td>
<td>93</td>
<td>96</td>
<td>YES</td>
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<tr>
<td>Sludge metallurgic</td>
<td>Slag</td>
<td>23</td>
<td>33</td>
<td>6</td>
<td>NO</td>
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<tr>
<td>Ash leaching 1</td>
<td>CaP</td>
<td>80</td>
<td>95</td>
<td>95</td>
<td>YES</td>
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<tr>
<td>Ash thermochem Na2CO3</td>
<td>Ash</td>
<td>93</td>
<td>86</td>
<td>99</td>
<td>YES</td>
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<td>Ash thermochem MgCl2</td>
<td>Ash</td>
<td>47</td>
<td>48</td>
<td>28</td>
<td>NO**</td>
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<tr>
<td>Sewage sludge ash</td>
<td>Ash</td>
<td>31</td>
<td>41</td>
<td>16</td>
<td>NO</td>
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<tr>
<td>Sewage sludge, chem-P</td>
<td>Sludge</td>
<td>53</td>
<td>67</td>
<td>95</td>
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<td>Sewage sludge, EPBR</td>
<td>Sludge</td>
<td>87</td>
<td>102</td>
<td>90</td>
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<tr>
<td>TSP</td>
<td>TSP</td>
<td>100</td>
<td>100</td>
<td>92</td>
<td>YES</td>
</tr>
</tbody>
</table>

*Die off of plants in two pots and limited growth in another two at pH 5 first year. >80% RFE at pH 7.

** >80% RFE at pH 5
Contaminants in recovered materials

- Contaminants limited in German fertilizer regulation measured
- PCDD/F, dl-PCB, PAH, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn
- All recovered materials fulfill the strict German fertilizer regulation with regards to heavy metals. Some above Swiss limits.
- TSP also above these limits.
- Organic contaminants measured only for struvite and are within German limits.

<table>
<thead>
<tr>
<th>Recovered material/ Legal limit</th>
<th>Source/ Measurement</th>
<th>No.¹</th>
<th>P₂O₅ total g/kg DM</th>
<th>As mg/kg DM</th>
<th>Cd mg/kg DM</th>
<th>Cr mg/kg DM</th>
<th>Cu mg/kg DM</th>
<th>Hg mg/kg DM</th>
<th>Ni mg/kg DM</th>
<th>Pb mg/kg DM</th>
<th>Zn mg/kg DM</th>
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<tr>
<td>Chem RRV (CH)</td>
<td></td>
<td></td>
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<td></td>
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<td>DmMV (DE)³</td>
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<tr>
<td>AirPlex</td>
<td>Average²</td>
<td>3</td>
<td>262</td>
<td>1</td>
<td>0.25</td>
<td>16.4</td>
<td>42.4</td>
<td>0.23</td>
<td>15.9</td>
<td>12.5</td>
<td>89.8</td>
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<td>Pearl/Struvia</td>
<td>Average²</td>
<td>3</td>
<td>300</td>
<td>2.7</td>
<td>0.1</td>
<td>2.7</td>
<td>2.6</td>
<td>0.39</td>
<td>2.5</td>
<td>1.3</td>
<td>14.9</td>
</tr>
<tr>
<td>Gifhorn (Hermanussen et al. 2012)</td>
<td>Average²</td>
<td>1 (&lt;5)</td>
<td>252</td>
<td>-</td>
<td>0.2</td>
<td>1.5</td>
<td>11.5</td>
<td>0.2</td>
<td>1.7</td>
<td>1</td>
<td>23.7</td>
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<tr>
<td>Stuttgart</td>
<td>Average²</td>
<td>2</td>
<td>230</td>
<td>1.6</td>
<td>0.43</td>
<td>4.2</td>
<td>30.4</td>
<td>0.32</td>
<td>4.7</td>
<td>6.5</td>
<td>47.2</td>
</tr>
<tr>
<td>Mephrec</td>
<td>Average²</td>
<td>2</td>
<td>100</td>
<td>4.7</td>
<td>0.28</td>
<td>109.5</td>
<td>115</td>
<td>0.67</td>
<td>17</td>
<td>4.2</td>
<td>85.1</td>
</tr>
<tr>
<td>Leachphos (Stemann et al. 2014)</td>
<td>Average²</td>
<td>1</td>
<td>300</td>
<td>10.1</td>
<td>3.8</td>
<td>34</td>
<td>851</td>
<td>0.2</td>
<td>13.8</td>
<td>25</td>
<td>1390</td>
</tr>
<tr>
<td>Ecophos (Herzel et al. 2014)</td>
<td>Ecophos</td>
<td>1</td>
<td>177</td>
<td>4</td>
<td>0.37</td>
<td>127</td>
<td>601</td>
<td>0.7</td>
<td>56</td>
<td>59.8</td>
<td>1737</td>
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<tr>
<td>Average TSP</td>
<td>(Remy 2010)</td>
<td>1</td>
<td>485</td>
<td>3.7</td>
<td>26.8</td>
<td>288</td>
<td>27.3</td>
<td>0.04</td>
<td>36.3</td>
<td>12</td>
<td>489</td>
</tr>
</tbody>
</table>

Source: P-REX Deliverable 9.1: Risk assessment
Environmental and cost assessment

- Sludge and sludge water based processes, on WWTP

- Dried sludge and ash based processes
### Environmental impacts of P recovery from 1 Mio pe WWTP

<table>
<thead>
<tr>
<th>Pathways</th>
<th>Fossil energy demand</th>
<th>Eco-toxicity (USE-tox)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit per a [Mio MJ]</td>
<td>[Mio CTU]</td>
</tr>
<tr>
<td>Sludge disposal</td>
<td>-46</td>
<td>9.6</td>
</tr>
<tr>
<td>Sludge precipitation</td>
<td>-9.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Liquor precipitation 1</td>
<td>-5.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>Liquor precipitation 2</td>
<td>-4.8</td>
<td>-0.9</td>
</tr>
<tr>
<td>Sludge leaching 1</td>
<td>24.1</td>
<td>-2.0</td>
</tr>
<tr>
<td>Sludge leaching 2</td>
<td>51.6</td>
<td>10.0</td>
</tr>
<tr>
<td>Sludge metallurgic, integr.</td>
<td>-26.0</td>
<td>38.6</td>
</tr>
<tr>
<td>Ash metallurgic</td>
<td>-14.5</td>
<td>38.9</td>
</tr>
<tr>
<td>Ash leaching 1</td>
<td>2.7</td>
<td>147.0</td>
</tr>
<tr>
<td>Ash leaching 2</td>
<td>-6.1</td>
<td>-9.6</td>
</tr>
<tr>
<td>Ash thermo-chemical, integr.</td>
<td>-12.6</td>
<td>421.6</td>
</tr>
<tr>
<td>Baseline</td>
<td>Mono-incineration</td>
<td></td>
</tr>
</tbody>
</table>
Results cost assessment, standard size plants 1 or 2.5/2.7 Mio PE

- Ash leaching 2
- Ash thermochemical
- Ash leaching 1
- Sludge metallurgical
- Sludge leaching
- Precipitation
- Status quo monoincineration
- Status quo co-incineration
- Status quo agricultural use
- WWTP-based processes (cost independent of status quo)
Summary of environmental and cost assessment

- Impact dependent on the process and existing infrastructure, e.g. mono-co-incineration
- Environmental assessment
  - Pathways for P recovery have different environmental profiles, some can realize P recovery with overall environmental benefits.
  - Assessment result depends on the method used, e.g. Ecotox
- Cost assessment
  - Bad news: Cost influence per kg P mostly higher than mineral fertilizer cost
  - Good news: Costs influence per PE < 3% of wastewater disposal cost
Water and Resources - R&D at the Institute for Ecopreneurship
Institute of Ecopreneurship - facts and figures

- **Personnel**
  - 35-40 employees
  - Budget: above 2.5 Mio CHF

- **Lab budget**
  - Equipment: 300,000 CHF
  - Consumables + small equipment: 200,000 CHF

- **Projects**
  - More than 40 projects on-going (above 3.5 Mio CHF third-part funding)
  - (9 EU FP7, SNSF, CTI, UNIDO, GIZ, Ministry of economic affairs, Federal office of the environment, Ministry of Energy, Ministry of Health, etc.)

- 25 „peer-reviewed“ papers
Current FHNW projects on phosphorus recovery

- **PHOSforYOU** - Demonstration of Recovery and Recycling in Northwestern Europe (Interreg, 150 kCHF)
- **Inspirewater** - Recovery of phosphoric and sulphuric acid from pickling baths (H2020, 835 kCHF)
- **Passage** - Marketable phosphoric acid from sewage sludge ash (Swiss innovation fund)
- **Pyrolysis and thermal purification of heavy metals for phosphorus recycling** (2014-2016, Swiss innovation fund)
ESPP launched 2013, to address all aspects of phosphorus sustainability

- P resources, mining, processing
- P recycling (re-use, recovery)
- P use efficiency in crop & animal production
- Environmental impacts of P-losses
- Sustainable and safe food chain, farm to diet
- Bio-nutrients in the circular economy
A coalition for action

- Bring together industry, R&D, public authorities, stakeholders
- Shared vision for sustainable phosphorus in Europe
- **Dialogue & networking** of expertise and experience (= priority identified by ESPP members)
- Awareness building
- Access policy & regulatory developments
- Dissemination of innovation, business cases, value chains
**ESPP in action in Europe: Regulatory**

- **EU Fertiliser Regulation recast**: taking recovered nutrient products into account
- **EU fertiliser criteria development** (JRC):
  - ESPP drafts for struvite, biomass ashes and (underway) biochars
- **Nitrates Directive**: “processed manure”
- **Organic Farming Regulation**: proposed validation of recycled P products
- **REACH** (EU chemicals regulation):
  - Art 2(7)d “recovered” substances, by-products - exemption for digestates
- **BAT BREFs** (Industrial Emissions Directive):
  - waste incineration - pig & poultry production - water treatment
- **BEMPs**: EMAS (EU Eco-Management and Audit Scheme Regulation) “agriculture”
- **EIP-AGRI Focus Group proposal**: agronomic use of recovered nutrient products
- **Standards**: CEN SABE, ISO 275 …
Success story:
Ecophos P-recycling from sewage sludge

- Pilot plant operational Varna, Bulgaria
- Produce DCP (Di Calcium Phosphate) for fertilisers, animal feed
- Full-scale plant under construction Dunkerque, France
  capacity: 200 000 t/y DCP from low grade P-rock and ash
- Contract to treat 60 000 t/y ash from Netherlands (SNB – HVC Groep) = 4 000 t/y P

See SCOPE Newsletter 111 and www.ecophos.com
Recophos – ICL

- Electrothermal production of white phosphorus (P4) from sewage sludge / ashes
- High-value raw material for chemicals: fire safety, electronics, …
- Recophos FP7 pilot project
- Technology acquired by ICL March 2016

www.icl-group.com

Tokyo Oct. 30th/ Nov. 1st 2016 - n° 39

K. Langefeld, ICL. March 2016: After a successful pilot phase, ICL plans to proceed over time with four full scale units in Europe and in the US. The first full scale unit could be operational by 2018. The output from these units will be used as raw materials for ICL’s specialty businesses in the Food and Engineered Materials markets.
Market study - fertilizer industry

Fertilizer Industry

- Increase plant availability
- Concentration & cleaning
- Blending/Granulation
- Marketing and Sales

Value chain
Market study - recovery value chain

Fertilizer Industry
- Increase plant availability
- Concentration & cleaning
- Blending/Granulation
- Marketing and Sales

Value chain
Recovery
- Cleaning
- Concentration
- Increase plant availability
- Blending/Granulation
- Marketing and Sales

www.p-rex.eu
Using existing structures

Fertilizer Industry
- Increase plant availability
- Concentration & cleaning
- Blending/Granulation
- Marketing and Sales

Recovery
- Cleaning
- Concentration
- Increase plant availability
- Blending/Granulation
- Marketing and Sales

http://infranetlab.org

www.p-rex.eu

University of Applied Sciences and Arts Northwestern Switzerland
Swiss legislation on waste

- Landfill of organic materials forbidden since 2000
- Sewage sludge not used in agriculture since 2006
- Phosphorus recycling
  - New decree on solid waste since January 2016
  - Sewage sludge and meat and bone meal
  - 10 year transition period
Outlook drivers

- **World drivers**
  - Continued increase in demand
  - Gradual reserve depletion over the next decades leads to
    - dependence of EU, China and US on Morocco
    - potential increase in price and environmental impact

- **Policy in Europe**
  - Switzerland pioneers phosphorus recycling
  - German recycling obligation from sewage sludge pending, decision 2017
  - EU revision of fertilizer regulation
    - introduction of ash and struvite as raw materials planned
    - workable framework and limits not yet established
  - Sewage sludge in agriculture under pressure (urbanisation and distance, organic contaminants, consumer/ supermarket attitudes)
Outlook technology and volumes

- Current technical recovery volume
  - ~1000 t P/y recovered at ~20 WWTP as struvite
  - Ash used for fertilizer production or directly in agriculture
    - Manure >10’000 t P/y, especially chicken litter ash
    - Meat and bone meal, sewage sludge ash
- Switzerland: 6’000 t P/y from sludge and 3’000 t P/y from meat and bone meal
- Sewage sludge mono-incineration ash in Europe ~50’000 t P/y
  - Ecophos
    - Supply contract for ashes with 4’000 t P/y from SNB/ HVC
    - Construction of factory for DCP in Dunkerque, commissioning 2017
  - Several processes applicable, several pilots ongoing
- Struvite in fertilizer regulation and in REACH -> higher prices
- High yield struvite processes ready

EU 1550’000 t mineral P/y
Outlook Potentials

- Technical recycling to tap unused 700’000 t P/y (45% of mineral demand)
- Processing of manure (1’700’000 t P/y) and sewage sludge (150’000 t P/y) already used in agriculture
  - better storage
  - transport away from hotspots
  - clean, standardized products
  - improved plant availability and P/N

Supply
- European fossil P production
- Import

Demand
- Fertiliser
- Feed additives
- Detergents and soaps
- Other

Recovery potential
- Municipal sewage sludge
- Slaughterhouse waste
- Food-waste (household and retail)
- Demand uncovered

1550’000 t P/y
Thank you for your attention!

Contact: anders.naettorp@fhnw.ch
P-REX coordinator: christian.kabbe@kompetenz-wasser.de

We would like to thank all involved project partners and other contributors.

Download at www.p-rex.eu and soon at https://zenodo.org/:
Technical Factsheets for processes
Reports on processes, recovered materials, environmental impact and more
P-REX policy brief

2 min Video: http://vimeo.com/78539404

This project has received funding from the European Union’s Seventh Programme for Research, Technological Development and Demonstration under Grant Agreement no. 308645.