## BUSINESS MODEL 16

# Phosphorus recovery from wastewater at scale

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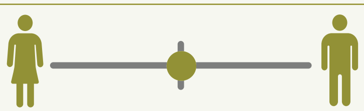
## Key characteristics

| | |
|---|---|
| **Model name** | Phosphorus recovery from wastewater at scale |
| **Locations** | Tested so far in 14 commercial installations worldwide (status January 2017) |
| **Waste stream** | Wastewater (sewage) |
| **Value-added waste product** | Recovery of phosphorus for reuse as clean-green fertilizer with environmental benefits |
| **Geography** | Any urban centre, applicable to a wide range of sewage treatment plants |
| **Scale of production** | Medium to very large; minimum plant size of 19 MLD sewage |
| **Supporting case in this book** | None (the case of urine collection in Ouagadougou, Burkina Faso is unrelated) |
| **Objective of entity** | Cost-recovery [ ]; For profit [X]; Social enterprise [ ] |
| **Investment cost range** | USD 2–5 million with a capex pay-back time of 3 to 7 years |
| **Organization type** | Public, private |
| **Socio-economic impact** | Enhanced compliance with environmental regulations, reduction in eutrophication and environmental pollution, cost savings for municipalities, reduced damage to public/municipal infrastructure, reduced financial costs for the society and potentially cost-efficient fertilizer reuse |
| **Gender equity** | Technology-wise no particular (dis)advantage for any gender  |

## Business value chain

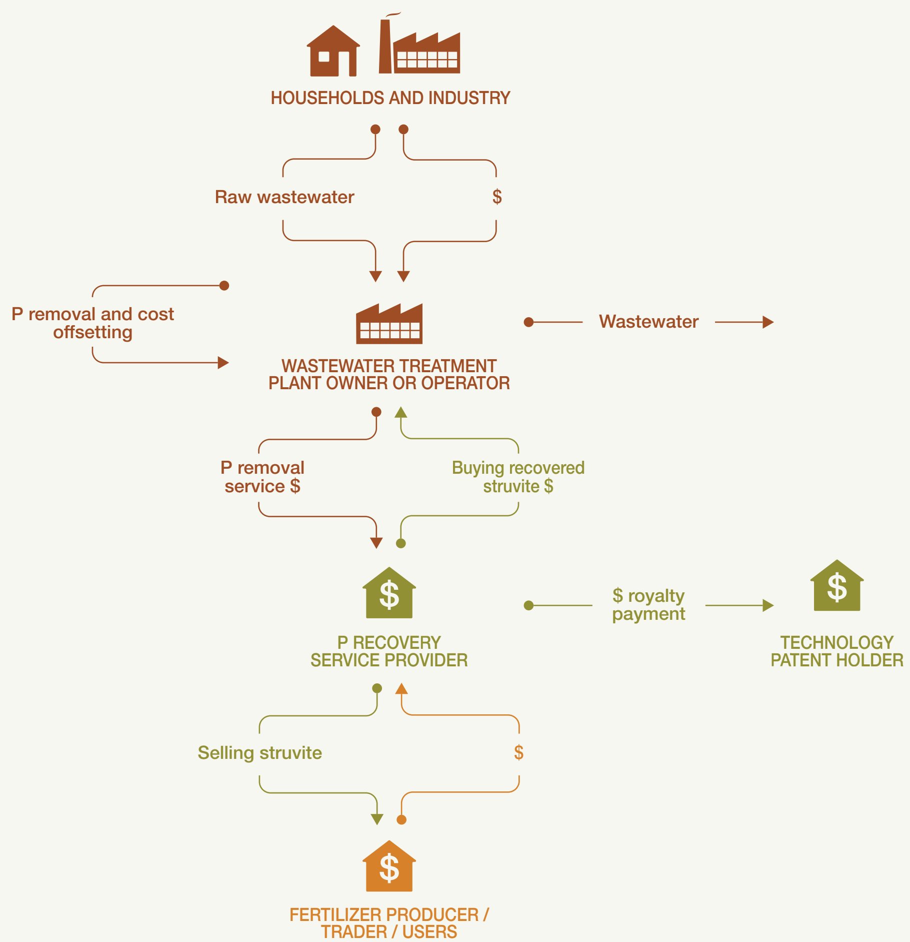
After food digestion, our ultimate ‘food waste’ is discharged as excreta into toilets and where toilets are connected to a sewer, sewage treatment plants become vast nutrient transformation hubs where depending on the technology significant amounts of nutrients can be extracted from the waste stream, ranging in the case of phosphorus (P) from 20% to over 80% of the P in the wastewater. The cost per unit of P recovered varies with the wastewater volume and P concentration and are significantly higher for smaller plants and for lower discharge effluent P concentrations. So far, the cost of recovered P exceeds the cost of natural rock-phosphate (Petzet and Cornel, 2013; Mayer et al., 2016) making P recovery financially not viable. As it is uncertain when rock-phosphate prices will change, and if the fertilizer industry will accept the new product[1], the double value proposition offered for example by Ostara is interesting. The Ostara technology, like similar ones, aims at P removal from the liquid generated from sludge dewatering. As the liquid (sludge liquor) feeds back into the treatment process, and contains a significant share of the overall P load, the removal of P in the return flow improves the biological nutrient removal performance of the treatment plant and prevents unplanned P crystallizing in the form of struvite[2]. The business concept is based on a PPP where Ostara is assisting the treatment provider in reducing its maintenance and disposal costs for P removal after its unplanned crystallization, while generating a high-quality slow-release fertilizer. The process offered by Ostara does not replace traditional sewage treatment, but can be (retro)fitted into the facility's existing treatment process (see http://ostara.com).

The benefits from the concept are multiple: the treatment plant saves costs, high enough to finance the investment, the captured phosphorus is of high quality (no contaminants) and can be marketed as fertilizer raw material, the functionality of the treatment plants is extended while its effluent meets (even better) environmental standards (Figure 203).

## Business model

This business model has a double value proposition. The first (and most important one) offers savings in treatment maintenance through an alternative P removal process; the second, a high-quality P

FIGURE 203. VALUE CHAIN SCHEMATIC – PHOSPHORUS RECOVERY FROM SEWAGE



crystal with potential use as fertilizer. The model is as such cost-driven for utility clients, and value-driven for resource sales. There are two models for financing the capital investment required for the P removal/recovery. Ostara offers its PEARL™ process based on either a traditional **capital purchase business model**, or through a **treatment fee model**. In the treatment fee model, Ostara pays for the installation and keeps ownership while the municipality or treatment plant operator (the client) runs the nutrient recovery process. Using a long-term contract, the client pays a monthly treatment fee based on agreed performance on phosphate removal. The treatment fee is lower than the costs of conventional phosphorus removal leading to immediate savings on operational costs. In the capital purchase model, the client pays for the installation and recovers the costs through maintenance savings usually over three to seven or max. ten years.

In both models, Ostara has a multi-year **purchase agreement** with the client to buy back the generated P crystals which are technically for the treatment plant a 'waste' product, while Ostara offers struvite marketing under the brand name Crystal Green™. In other cases than Ostara, the municipality might engage itself in fertilizer sales, be it for (green) image marketing or revenues. This, however, requires additional investments to enter the fertilizer market. In the case of Ostara's PEARL™ process, the struvite is generated as a side product which gives Ostara flexibility in its pricing and makes it relatively independent from the current rock phosphate price.

In alternative processes where P is, for example, extracted from the **ash** of mono-incinerated[3] sewage sludge, the P recovery can be much larger than from sludge liquor, but does not reduce the cost for the treatment plant, and has to be largely financed through P sales unless the recovery process is subsidized due to the environmental benefits. This dependency on the global rock-P price remains a challenge for the acceptance of several P recovery technologies, and most companies target premium (niche) markets with higher than usual willingness to pay. In general, ecological and economic benefits of closed loop concepts are not (yet) the driving force for the implementation of P recovery technologies, but financial advantages.

The business model described in this chapter presumes the operation for a standalone **private enterprise** (Figure 204). A largely complementary description of the Ostara case has been provided by P-Rex (2015).

## Potential risks and mitigation

**Market risks:** From the recovery enterprise perspective, the number of wastewater treatment plants currently being built, or already set up, without P recovery units is larger than what the suppliers of P recovery technology could satisfy. In this sense there is limited risk, especially as with increasing emphasis on the SDGs, environmental sustainability and a circular economy, the recycling market will certainly grow. There remains a risk of missing out on prestigious projects.

In view of the market for recovered P, there can be a variety of challenges which differ from country to country and are still limiting the potential of P recovery despite its obvious benefits:

1) In many countries a range of markets might not be accessible due to prohibitive legislations or missing legislation on the reuse of waste derived resources.
2) The volumes of the recovered P are still too small compared with the market size, which increases the costs of entering the current mainstream value chain.
3) Although many studies showed that recovered P crystals are of high quality, and show often even less micro contamination, e.g. with metals than natural rock phosphate, not only legislations but also the fertilizer industry is hesitant to accept the product, be it for blending of other P sources or as stand-alone slowly-soluble fertilizer.

**FIGURE 204. BUSINESS MODEL CANVAS – STRUVITE RECOVERY INTO PREMIUM GRADE P FERTILIZER (OSTARA TYPE)**

**KEY PARTNERS**

- Treatment plant operator
- Patent holder
- Fertilizer industry

**KEY ACTIVITIES**

- Capturing P from the treatment process
- Marketing and sales of recovered struvite
- Obtaining permits and certification for struvite marketing

**KEY RESOURCES**

- Technology for P recovery
- Ability to obtain legal permits for struvite sale

**VALUE PROPOSITIONS**

- A modular P removal systems and financing model to recover a non-renewable resource with a potentially high fertilizer value.
- Savings in M&O cost for chemically controlling unwanted P crystallization during the treatment process

**CUSTOMER RELATIONSHIPS**

- Direct contact with plant operators
- Technical support
- Direct contact with potential struvite traders

**CHANNELS**

- Direct sales of P technology
- Direct sales of fertilizer to traders

**CUSTOMER SEGMENTS**

- Treatment plant operator/ municipality
- Fertilizer market (so far mostly niche markets)

**COST STRUCTURE**

- Investment cost in P recovery unit
- Operational cost if run by enterprise
- Struvite collection/storage/marketing cost. Transaction costs related to the penetration of the fertilizer value chains with small P volumes
- Research & Development/validation/ licensing/certification

**REVENUE STREAMS**

- Sales of P technology
- Monthly treatment fees based on P removal
- Sales of premium grade P fertilizer

**SOCIAL & ENVIRONMENTAL COSTS**

- Uncertain acceptance of the product by traders and customers

**SOCIAL & ENVIRONMENTAL BENEFITS**

- Environment benefits from preventing eutrophication
- Supporting circular economy jobs and added-value via P (and N) recovery
- Extended life time of a finite resource
- Potentially a cheaper P source once rock-phosphate prices go up

4) More progressive legislation in support of a circular economy could help penetrate the conventional P market by demanding for a certain ratio of recovered to natural P; an example is one of the Indian Government which requires the fertilizer industry to co-sell bags of industrial fertilizer with a number of bags of waste-based compost.
5) To avoid perception related risks, marketing strategies normally avoid any connection between the name of the P product and its source.

6) With the never-ending generation of wastewater, also the supply of recovered P will be continuous irrespective of agricultural seasons. This will pose storage challenges unless multiple market segments next to seasonal crops are available (e.g. parks and gardens, forest or fruit plantations, year-round home gardens).
7) It is a significant advantage if like in the Ostara case the cost of P recovery can be (more than) absorbed by savings in conventional P removal, as the price of rock-phosphate is still too low compared with the break even price of recovered P, pushing recovered P into premium or niche markets which are able to pay higher-than-average prices.

P recovery from wastewater should be complemented with source separation. Capturing urine for example at large point sources (e.g. festivals) for nutrient recovery gives more flexibility to balance supply and demand, requires however similar to the case above legal support to enter established markets.

**Competition risks:** The number of providers of P recovery technology (and related patents) is increasing, and so is the diversity of processes supporting different treatment technologies, recovered amounts of P, and scales (WERF, 2010). Several companies have moved beyond technical pilots and are now competing on the market. However, compared to conventional suppliers of wastewater treatment technology, and demand for new plants, the internationally competitive group specialized on P recovery is still small. Where the enterprise partner has obtained a license from the patent holder, it needs to be understood how stringently the license is restricting similar business and upscaling. Patenting might open business avenues, while new technologies will continue to evolve. Competition risk is highest from the conventional P market where rock-P dominates in quantity, price-wise and is favoured also in view of some physical properties. Moreover, conventional P fertilizer might be subsidised, a benefit which is not easily applicable to a waste-derived product. Over time, it is anticipated that a higher rock-P price will help to stimulate P recovery.

**Technology performance risks:** Most P recovery technologies on the market have been repeatedly tested and produce a high quality final products. As the recovery potential between the technologies varies significantly (see Figure 280 in chapter 19) as does the cost-effectiveness (Sartorius et al., 2012; Petzet and Cornel, 2013), the municipality has to choose the one most appropriate for its plan, be it preventing unplanned struvite crystallization and/or compliance with P recovery targets. Where urine is collected with UDDTs their maintenance requires attention. Logistical challenges for urine storage and transport could be solved through low-cost innovations in urine dehydration (e.g. Senecal and Vinneras, 2017).

**Political and regulatory risks:** The regulatory context is in many countries not yet supporting 'secondary' phosphorus containing fertilizers and their producers as it is often classified as waste (P-Rex, 2015). While stringent environmental regulations on the discharge of P effluents into water bodies are on the increase and provide an opportunity to promote recovery and reuse, and so do SDG 12.4 and 12.5, these regulations mostly favour P removal, but not yet recovery and reuse. In fact, in Europe, regulations on the reuse of waste derived resources, including urine and struvite, are often very restrictive (Winkler et al. 2013). On the other hand, in many developing countries, regulations and standards might be lacking which can place resource recovery and reuse in a grey area where entrepreneurs might have an easy go, but quality control and legal security remain risk factors. However, with increasing attention to the SDGs and a circular economy the situation is changing, especially in Europe (Box 6).

**Social equity related risks:** There are no social risks with the model or technology, unless urine diverting toilets are targeted and household urine collection which might add to the workload of those

## Box 6. P-recovery regulations and obstacles in Europe

Switzerland was the first European country to make phosphorus recovery and recycling from sewage sludge and slaughterhouse waste obligatory. The new regulation entered into force on 1.1.2016 with a transition period of 10 years. Switzerland banned direct use of sewage sludge on land in 2006, so that the new regulation will lead to obligatory technical recovery and recycling in the form of inorganic P products. Swiss sludge and slaughterhouse waste together represent an annual flow of 9100t of phosphorus.

In Germany, a new sewage sludge ordinance (AbfKlärV) is expected to enter into force early 2018, making phosphorus recovery obligatory for larger sewage works within 12 years (> 100 000 p.e.) or 15 years (> 50 000 p.e.), under certain conditions. P-recovery will thus be required for around 500 sewage plants, treating around 2/3 of German sewage. Following the legislative developments in Switzerland and Germany, Austria is now also opting for mandatory P recovery from municipal sewage sludge. The draft Federal Waste Plan 2017 (Bundes-Abfallwirtschaftsplan) includes a ban of direct land application or composting for sewage sludge generated at Wastewater Treatment Plants (WWTP) with capacities of 20,000 p.e. or above within a transition phase of 10 years. Alternatively, these WWTP will have to recover the P from sludge or its ash. This regulation will cover 90% of the P contained in the Austrian municipal wastewater.

However, P recovery within a Circular Economy requires reuse. Until now, struvite recovered from wastewater is only authorised for use as a fertilizer for some producers in some countries (e.g. the Netherlands, Denmark and Japan), or only on a case-by-case (e.g. Ostara plant by plant) authorization. Even in a country like the Netherlands, approval as a fertilizer does not ensure for struvite the ***End-of-Waste*** status. End-of-waste criteria specify when certain waste ceases to be waste and obtains a status of a product (or a secondary raw material). This current lack of clarity and disparities even between EU Member States poses a significant obstacle also to investments in the technology as long as it cannot necessarily be sold in another country, because the resulting product cannot be sold as a fertilizer.

The currently (2017) discussed new EU Fertilisers Regulation will enable recycled nutrient products to be sold in any Member State, when the new Regulation comes into force. Recognised products will also be granted de-facto End-of-Waste status. Composts and digestates are already included in the proposed Regulation text, but struvite is not. The EU's Joint Research Centre (JRC) has been mandated to make an impact assessment and (if this concludes positively) to propose criteria to add struvite, biochars and ash-based recycled nutrient products to the new Regulation annexes.

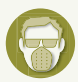
Source: http://phosphorusplatform.eu/

culturally in charge of household waste and sanitation. At larger scale, mineral fertilizer recycling not only saves jobs in the long term, but also creates additional green jobs and industries. As further increases in the price of rock-phosphate (based fertilizer) will hurt poorer countries first, the suggested resource recovery options – especially those with guaranteed cost recovery – could provide a low-cost alternative.

**Safety, environmental and health risks:** The industrial production of struvite shows good safety records, and the final product is usually of high purity for direct application in agriculture (Table 47).

There can however be variations in the heavy metal content with some of the technologies (Egle et al., 2014). Urine-based fertilizer is P and N rich and requires as a liquid fertilizer precaution. Although urine is per se sterile, there is a limited risk if it is collected from unhealthy people or if there is cross-contamination with fecal material. A higher risk from farmers' point of view is its unpleasant smell, and high pH which can damage crops if applied undiluted or too often. Guidelines for handling urine related risks, also in farming have been presented by Richert et al. (2010) and Stenström et al. (2011).

**TABLE 47. POTENTIAL HEALTH AND ENVIRONMENTAL RISK AND SUGGESTED MITIGATION MEASURES FOR BUSINESS MODEL 16**

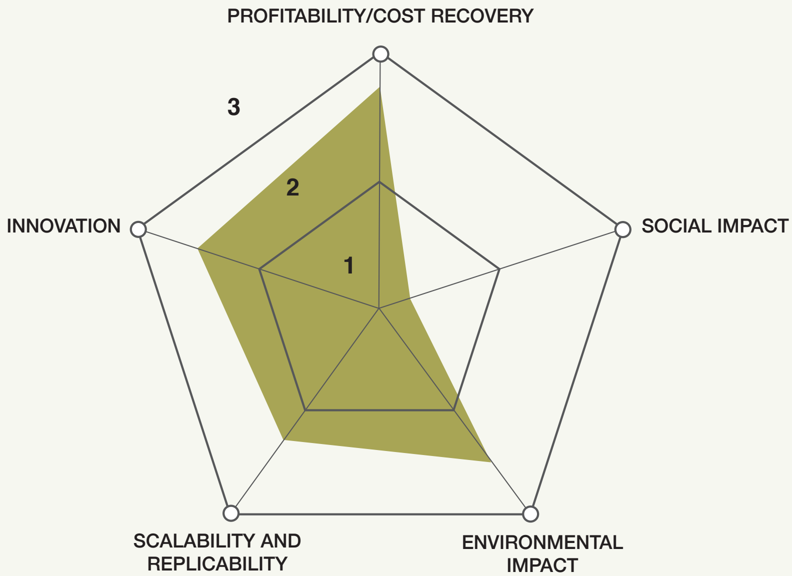
| RISK GROUP | EXPOSURE | | | | | REMARKS |
|---|---|---|---|---|---|---|
| | DIRECT CONTACT | AIR/ ODOR | INSECTS | WATER/ SOIL | FOOD | |
| Worker | | | | | | Independently of the struvite recovery, workers at sewage plants face the relatively highest risk |
| Farmer/user | | | | | | |
| Community | | | | | | |
| Consumer | | | | | | |
| Mitigation measures |  |   |  |  | | |

Key: NOT APPLICABLE · LOW RISK · MEDIUM RISK · HIGH RISK

## Business performance

P recovery technologies are on the increase. Currently, technologies with the highest economic viability for P removal during the treatment process has a cost recovery pay-back time of up to seven years. Other technologies, where P is recovered at the end of the treatment process, are financially struggling, although the P recovery percentage can be much higher. The reason is that their revenues depend – if not subsidized – on the P market price which is so far too low to compete and break even (Cornel and Schaum, 2009; Molinos-Senante et al., 2010). Thus, from the perspective of resource recovery, some of the best recovery rates are only viable when all aspects are considered, including economic, environmental and social (Balmer, 2004). In industrialized countries, a push for circular economics are expected to drive the establishment of P recovery (Sartorius et al., 2012), while the tipping point when the price of rock P exceeds the cost of P recovery remains uncertain (Horn and Sartorius, 2009). As in addition the legal framework for the reuse of resources recovered from waste remains a challenge, business models like the one of Ostara have significant advantages as their viability is independent of the P market. In general, the PPP model as run by Ostara has, except for smaller treatment plans, high replication potential. The prospects of cost recovery for the public partner and the win-win perspectives for both partners outshine the possible challenges of entering the fertilizer value chain for the generated struvite. The model ranks high on innovation, profitability and positive environmental impacts, but low on social impact (Figure 205).

**FIGURE 205. RANKING RESULTS FOR A PPP MODEL IN SUPPORT OF P RECOVERY DURING WASTEWATER TREATMENT**

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*Case descriptions are based on primary and secondary data provided by case operators, insiders or other stakeholders, and reflect our best knowledge at the time of the assessments 2014/15. As business operations are dynamic, data can be subject to change. More recently, for example, Ostara added the WASSTRIP (Waste Activated Sludge Stripping to Remove Internal Phosphorus) process to its technology solutions. See http://ostara.com/nutrient-management-solutions/.*

## Notes

1 Some resistance had been explained with the characteristics of recovered P crystals, like their slow solubility as well as regulatory challenges (see box 6 and chapter 19).

2 The spontaneous and unplanned formation of struvite in treatment plants affects pipes and other inner surfaces of the treatment process, making operation of the plant inefficient and costly because the struvite must be dissolved with sulphuric acid or broken down manually.

3 “Mono-incineration” means that the sewage sludge is incinerated separately, not mixed with municipal solid waste or other waste, and the ash contains high phosphorus levels (up to 7% P).