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An Exploration of Barriers for Commercializing Phosphorous Recovery Technologies

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Abstract

Phosphorous is an essential element in sustaining modern day farming practices and is expected to deplete within the next 100 years. However, phosphorous utilisation efficiency in most countries is below 20%, making the implementation of suitable phosphorous recovery technologies urgent and necessary. In spite of intensive research and development, there are only a few commercial recovery facilities being implemented. Therefore, there is a need to identify potential roadblocks/hurdles in a systematic manner. To this end, technology readiness level, process economic and sensitivity analyses were novelly integrated and employed to assess the opportunities and hurdles during the implementation of current phosphorous recovery technologies. The enhanced feasibility assessment methodology is demonstrated via a case study, revealing that only struvite crystallization is sufficiently mature to be industrially implemented. Under most scenarios evaluated, struvite crystallization can be profitable or break-even if financial assistance is provided from policy-makers. Sensitivity analysis showed that overall profitability is highly sensitive to raw materials cost and product sale price, while phosphorous concentration in waste streams has less effect. Such an assessment could be extended to identify barriers in other resource recovery technologies.

Keywords: Phosphorous recovery; Struvite crystallization; Technical readiness level; Net present value; Sensitivity analysis

1. Introduction

Phosphorous (P) is an essential macro-nutrient for cells, crops, living animals and human beings. Nearly all phosphorous being used is sourced from industrial phosphate rock. In 2017, nearly 70 million tons of phosphate rock (P_2O_5 equivalent) were consumed, while the total resource is predicted to deplete within the next 100 years (Elser et al., 2011; Li et al., 2018). However, phosphorous utilisation efficiency in most countries is below 20% (Li et al., 2015), meaning more than 80% losses. Such significant losses increase the phosphorous concentration in local streams, and cause environmental problems such as eutrophication and red tide. What is more, the world's population is to increase to 9 billion by 2050 (Samir et al., 2017), meaning additional food requirements, and therefore additional phosphorous is required. Phosphorous recovery provides an opportunity to minimise the environmental impact and to reduce the amount of phosphate rock mined. It has therefore drawn significant attention over the past two decades.

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To date, more than 30 phosphorous recovery technologies have been investigated (Cieślik et al., 2017), most of which have been triggered by environmental restrictions (sustainability and resource efficiency), concerns regarding the finite and geopolitical considerations surrounding phosphate deposits, and the increase of phosphate rock price. An ideal phosphorous recovery technology would feature a high recovery rate, low capital and operational cost and useful by-product with less environmental risks (Egle et al., 2015). However, most previous studies focus on the reaction mechanisms (Li et al., 2016; Zamora et al., 2016; Huang et al., 2018), while some of them are economically unjustified or designed in a way that cannot be easily implemented (Egle et al., 2015). This makes the application of recovery technologies in a given stream complicated, not only because of the differences in process layouts and requirements, but also the variations in waste volume, phosphorous concentrations, phosphorous forms (for example, chemically, orthophosphate or organically bonded) and interfering components (for example heavy metals, organics and pathogens).

Therefore, an assessment framework to identify potential roadblocks/hurdles for the commercialization of phosphorous recovery becomes necessary. Azapagic et al. (2016) introduced a sustainable production and consumption framework named DESIRES, where the economics, environmental and social sustainability criteria were applied to evaluate the efficiency of electricity generation in the United Kingdom. Tura et al. (2019) applied a multiple-case study approach including environmental, economic, social, political and institutional, technological and informational, supply chain, and organizational factors to identify the drivers and barriers for developing new business in circular economy. Similar criteria were also used by Luthra et al. (2017) for supply chains. Udugama et al. (2017) and Mansouri et al. (2017) discussed the techno-economic considerations of resource recovery from bio-based processes, as well as the specific challenges and opportunities. While evaluation criteria in those works apply in some degree to phosphorous recovery, key aspects such as variations in waste streams, the influence of pre-treatment processes and identification of control variables for performance improvement and cost reduction are different. What is more, the large number of available technologies (over 30 for phosphorous recovery technologies) make the data collection and selection of a suitable technology time-consuming. Xia et al. (2019) established a comprehensive barrier identification system for green technology adoption. However, lack of data in phosphorous recovery operational stage also make the operational level assessment difficult.

In this study, we define phosphorous recovery technologies as processes that recover bioactive phosphate with contaminates (e.g. trace element, organics) satisfying legal requirements. Although regulations vary across different regions, processes with well-known negative environment effect in the literature are ignored. For example, direct application of sewage sludge onto agricultural land is not considered due to the existence of organic contaminants, heavy metals and pathogens. At the same time, phosphorous enrichment (for example, absorption and the traditional Enhanced Biological Phosphorous Removal Process) and phosphorous release (for example, thermal hydrolysis, microwave treatment and supercritical water extraction) processes are excluded. With these limitations in mind and the multi-faceted considerations required, a new technology assessment framework considering technology readiness level (TRL) assessment, process economics and sensitivity analyses are proposed (Section 2). This framework differs from previous research as it extends traditional TRL assessment to a two-step system based on expert knowledge and widely available literature, and introduces the design of experiments for sensitivity analysis in an evaluation framework. The framework was then applied to a case study, where the applicability of the framework and barriers for current commercialisation of phosphorous recovery technologies were discussed. The development framework can be used to direct scientific research, formulating industrial policy and assisting investments in the future.

2. Methodology

A systematic, hierarchical methodology was developed, taking into account decision gates of waste stream characterisation, technology readiness level and economic analysis. The proposed methodology has an enhanced Technology Readiness Level (TRL) step and has also incorporated a sensitivity analysis to identify key operating parameters, and to investigate the influence of market and economic variations on the process profitability. Figure 1 is an overview of the framework, which was illustrated using information from the Oxley WWTP in Queensland, Australia (Shu et al., 2006) as a case study. This plant is a conventional BOD-removal activated sludge plant with an average dry weather flow rate of 550,000 M^3/day, which contains 4-14 mg/l PO_4^{3-} phosphorous (Münch et al., 2001).

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Flyttet opad [1]: Direct application of sewage sludge onto agricultural land is not considered, as the existence of organic contaminants, heavy metals and pathogens are strictly restricted by legal regulations.

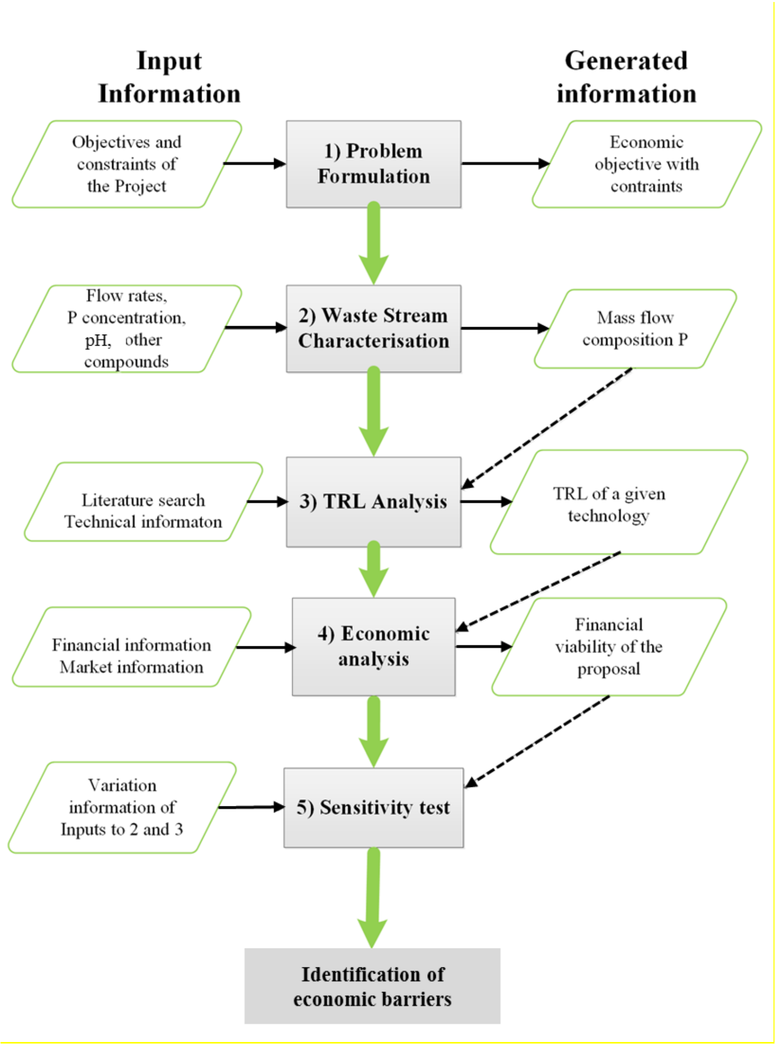

Figure 1: Proposed enhanced hierarchical techno-economic methodology for efficiently assessing the barriers to commercialising P-recovery technologies

2.1 Step 1: Problem Formulation

Equation 1 describes the objective function (objective) of this framework and the constraints,

$$\max \boldsymbol{NPV}_{\boldsymbol{F.C.F}} \left(\boldsymbol{P.recovery}_{\cdot \boldsymbol{Technology}}, \boldsymbol{Conditions}_{\boldsymbol{Steam}} \right) \qquad (1)$$

$$Subject\ to\ \boldsymbol{P.recovery}_{\cdot \boldsymbol{Technology}} \geq \boldsymbol{min\ TRL}$$

The objective of this framework is to identify P recovery technology ($P.rec_{\cdot Technology}$) that gives the highest Net Present Value (NPV) of Future Cash Flows ($NPV_{F.C.F}$) in a given P waste stream

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$(Conditions_{Steam})$, which is subjected to the constraints of a minimum Technology Readiness Level $(min\ TRL)$ that is practically feasible for implementation.

2.2 Step 2: Waste Stream Characterisation

In a given waste stream, volume/ mass flow rate, elemental concentrations together with the total amount of phosphorous available need to be quantified. This information makes the first stop/go decision by the user. If the available mass of phosphorous is deemed too low by the user, the stream will not be suitable for phosphorous recovery.

2.3 Step 3: Technical Readiness Level (TRL)

Technology screening of a given stream not only depends on its capabilities, but also on the level of technology maturity (Rybicka et al., 2016). This is of relevance to many technology development projects as significant work needs to be carried out to transition a technology that has been demonstrated at lab scale to a commercial product. Technology maturity can also be used to put into perspective the additional risks (both economically and operationally) a project takes on, when installing a novel technology that is still under development. To standardise this decision making process, concepts such as Technology readiness level (TRL) have been developed. Technology readiness level (TRL) is a matrix that was originally developed by NASA to assess space technologies and since has found wide spread use in other areas of technology development (Rybicka et al., 2016). Equipped with the TRL matrix, the state of development of a given technology can be determined and an informed decision can be made about the operational and economic risks that a given technology may bring to a project. The information gained through the application of TRL matrix is also compatible and complimentary to the management based approach of innovation lifecycle that is a used to understand new technology development in social sciences and business management(xxx). However, the TRL matrix in comparison to innovation lifecycle takes a more technical approach in its analysis. In the context of phosphorous recovery, TRL can be employed systematically to compare the technology maturity of different phosphorous recovery technologies and make an informed decision about the current level of maturity of these technologies and what risks it may bring to a phosphorous recovery project. Detailed definitions of TRLs are listed in Table 1 (Modified from Parasuraman, 2000).

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Table 1: Definition of different TRLs

TRL	State of Development
1	Basic principle observed and reported
2	Technology concept / application formulated
3	Analytical and experimental critical function / Characteristic proof - of - concept
4	Component and / or breadboard validation in lab
5	Component and / or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in relevant environment
7	System prototype demonstration in relevant environment

8	Actual system completed and qualified through demonstration
9	Actual system proven through successful mission operations

To categorize TRL, a TRL range was firstly assigned based on the number of occurrences in literature. A thorough literature review is necessary. It helps to understand where information is available, and where it is lacking. A guideline for this first assessment is based on Rybicka (2016):

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- A TRL of 1-3 is assigned for technologies that only have lab scale application. Lab scale is defined as work conducted in a lab setting and at bench scale primarily working on attaining a proof of concept.
- A TRL of 4-6 is for a technology that has both lab and pilot scale applications. Pilot scale is defined as work that was conducted on developing a robust process (either in a lab or at pilot scale) and the concept is proven and mechanisms are well documented.
- A TRL of 7-9 is for technologies that are at full-scale application, which is defined as the implementation of a phosphorous recovery technology at an industrial site such as a waste water treatment plant.

In order to further refine these TRL ranges to a single TRL score, the authors propose the following factors should be considered: process awareness, technical ‘knowhow’ and number of applications in each category (e.g. lab, pilot and full scale) in literature at a given TRL range. The numbers of occurrences of applications will be considered at a high level if there are over five applications recorded, a medium level for one to five records and low when no application is found. Process awareness will be at a high level if the reaction/separation mechanisms are completely understood, a medium level if reaction mechanisms are somewhat known and at a low level if few reaction mechanisms are reported. A high technical ‘knowhow’ is based on well-established sub-technologies, such as traditional membranes or composting. If the basis of the sub-technologies used is recent developments with several pilot/full-scale demonstration plants, a medium level will be assigned. A low technical ‘knowhow’ level will be assigned if a technology is novel. The above-mentioned levels for different factors will be used to determine a TRL score based on its corresponding TRL range (shown in Table 2). The addition of this second level of refinement allows an interested user to easily assess the final TRL of a given technology while reducing the ambiguity of this judgement.

Slettet: These above TRL ranges are further refined to TRL scores based on three factors:

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Table 2: Deciding the final TRL

TRL range	Process awareness	Technical ‘knowhow’	Number of applications	TRL score
1-3	Low	Low	Low	1

	Low to medium	Medium	Low	2
	Medium	Medium	Low	3
4-6	Medium	Low	Low	4
	High	Medium	Medium	5
	High	At least one factor is High		6
7-9	High	Low	High	7
	High	Medium	Medium	8
	High	At least one factor is high		9

The stop/go criterion in this step is the identification of an applicable process technology that is of a sufficient TRL. In the context of this work, the authors would define TRL 7 or above as sufficient, as technologies at these TRL's have been tested at industrial scale.

2.4 Step 4: Economic Analysis

Even with a high TRL score, a technology can be infeasible if the cost of raw material, utilities and maintenance are higher than revenues derived. In the context of phosphorous recovery, process costs ($Cost_{p,recovery}$) are from chemical dosage (assessed based on stoichiometry), product refining, energy, maintenance and staff salary, while the revenue ($Revenue_{p,recovery}$) is affected by phosphorous concentrating ratio, struvite recovery efficiency and product sale price (shown in Equation 2). Capital investments such as land purchase and equipment cost have been ignored due to their significant variation across different regions.

$$Net\ Income = Revenue_{P.recovery} - Cost_{P.recovery} \quad (2)$$

The net present value (NPV) is used in capital budgeting to analyze the profitability of a projected investment. A positive value reflects the project is self-sustainable. It is a function of annual net income, discount rate (r) and project payback period (n). In this analysis, we will only analyze the Present Value (PV) of future cash flows as this value can be used to make decisions of a project's viability and compare different operating and economic regimes without the need to carryout complicated and often erroneous capital investment calculations

$$PV = net\ income\ (1 - \frac{1}{(1+r)^n})/r \quad (3)$$

2.5 Step 5: Sensitivity Analysis

Sensitivity analysis is an essential step to identify key barriers for the commercialisation of phosphorous recovery technologies. Design of experiments (DoE) greatly reduces the number of test runs without sacrificing information on the main effects. Therefore, a 2nd order factor interaction function in DoE are used to investigate what main factors make phosphorous recovery infeasible. QQ plots are used to compare distributions between designed conditions and the 2nd order function model. Analysis of variance (ANOVA) is applied to identify sources of variation. Factor values with a p-value below 0.05 were considered to be significant (Ye et al., 2010). To show the validity of fit of the polynomial functions, the co-efficient of determination (R^2) and the adjusted co-efficient (R^2adj)were used. R^2 illustrates how much of the observed variability in the data is explained by the model. R^2adj modifies R^2 by considering the number of predictors in the model. Based on the above, the influence of variations in waste stream compositions, market, operating and financial information on NPV were analysed. This information can then be used to direct future scientific research.

3 Results and Discussion

3.1 Step 1: Problem Formulation

The case study is to find the maximum Present Value (NPV) of future cash flows that can be generated by a phosphorous recovery technology for the Oxley WWTP, using technologies that have a TRL of 7 or above.

3.2 Step 2: Stream characterisation

Conditions used in the case study are documented in Section 3.4.

3.3 Step 3: Technology search and TRL analysis

A thorough literature review was conducted using the Web of Science database. While we acknowledge this is not an exhaustive literature survey, it is a comprehensive one, with over 945 papers analysed, and the relative number of papers indicates levels of process awareness, technical ‘knowhow’ and occurrence of full-scale applications. A general conclusion regarding the technology readiness of current state of art technologies was then drawn. Techniques and processes with potential for full-scale implementations or which are already implemented are summarised in Table 3.

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$$R^2 = 1 - \frac{SS_{residual}}{SS_{model} + SS_{residual}} \qquad (4)$$

$$R^2{}_{adj} = 1 - \frac{n-1}{n-m}(1-R^2) \qquad (5)¶$$

where, SS is sum of squares, n is the experiment number and m is the number of model terms excluding constants.

Table 3: Overview of current P recovery processes and technologies

Process	Advantages	Disadvantages	Technology	Product	Source	Reference
Composting(C)	● Low Cost ● Onsite Recovery	● Long stabilization time ●Contamination	Traditional composting	A	OW	Cieślik et al., 2017
			Vermicomposting	A	OW	Cieślik et al., 2017
Struvite Crystallization (S)	● Slow release fertilizer ● Reduces sludge volume ● Reduces nutrient load	● Increases capital cost ● Economics unclear	AirPrex®	B	DSL	Kataki et al., 2016
			NuResys®	B	DS	Schoumans et al., 2015
			Ostara®	B	DS	Cieślik et al., 2017
			Phospaq®	B	DS	Egle et al., 2015
			STRUVIA	B	Ds	Egle et al., 2015
Biomineralization (B)	● Little Mg required	● Long stabilization time	-	B	Urine	Simoes et al., 2017
Incineration (I)	● High efficiency	● High capital cost	-	C	SS	Cieslik et al., 2014
	● Reduces waste volume	● High energy cost	-	C	SS	Egle et al., 2015
Calcium P (CP)	● Low Cost ● Implemented easily ● Onsite Recovery	● Limited application	Filter substrate	D	SA	Loganathan et al., 2014
			RecoPhos®	D	SA	Arnout et al., 2016
			LOTUS	D	SA	Egle et al., 2015
Gasification (G)	● High efficiency	● High capital cost	Thermphos®	E	SA	Ribarova et al., 2017
	● produces pure P element	● High energy cost	InduCarb®	E	SA	Arnout et al., 2016

A: Composted Biomass, B: Struvite, C: Incinerated Ash, D: Calcium P, E: Pure P
OW: Organic Waste, DSL: Digested Sludge, DS: Digester Supernatant, SS: Sewage Sludge, SA: Sludge Ash

3.3.1 Current State of P-recovery technologies

Composting is a traditional worldwide biomass/waste management process using microorganisms or earthworms to break down green waste (leaves, food waste, and animal waste) into humus after weeks or months. Modern, methodical composting is a multi-step, closely monitored process with measured inputs of water, air, and carbon- and nitrogen-rich materials. The composted solid waste is rich in phosphorous and other nutrients and could be either directly used as soil mixes or fertiliser after further treatment.

Struvite crystallization is a wastewater phosphorous recovery technology with the potential to ease both the scarcity of phosphorous rock resources and eutrophication. Recovered phosphorous could be applied to soil at rates greatly exceeding those of conventional fertilizers without burning plant roots (Kataki et al., 2016). This technology has been tested in various wastewater streams, reactors (Rahaman et al., 2014; Melia et al., 2017) and operating conditions (Kumar et al., 2015, de Luna et al., 2015). Combinations with pre-treatment and post-treatment processes have also been investigated.

Biomineralization is a potential phosphorous recovery technology that produces minerals in the presence of living organisms. Phosphorous is recovered in the form of struvite or hydroxyapatite. Biomineralized phosphate shows higher recycle potential with less external chemical addition (Soares et al., 2014) and allows more flexible influent composition (for example, phosphorous concentrations in the influent could be as low as 10 mg/L). *Myxococcus xanthus*, *Bacillus pumilus*, *Halobacterium salinarum* and *Brevibacterium antiquum* have been tested for potential phosphorous recovery. *Bacillus pumilus* and *B. antiquum* are capable of growing and producing bio-minerals identified as struvite that reached up to 250 μm in size within ten days (Li et al., 2017).

Incineration followed by chemical extraction produces calcium phosphate as a by-product. HCl, HNO_3, H_2SO_4, critic or oxalic acids have been intensively reported to extract phosphorous from incinerated ash. Such extraction is normally completed in 100 minutes with phosphorous, K, Ca, Mg and S as main ingredients. It has been proven that sulphuric acid extraction ends up with the least amount of heavy metal, due to fewer complexation reactions when compared with other acids (Egle, et al., 2015). Nakakuno (Nakakuno et al., 2012) reported that caustic soda could be used to remove heavy metals from the extraction process, however, the process efficiency reaches only 40%. Phosphorous in sludge ash could also be recovered similarly, which was proven by ICL Fertilizers (Egle, et al., 2015).

Gasification is another pathway for phosphorous recovery. Typically, raw phosphate or ash is fed into an electric arc-furnace at temperatures over the ash’s melting point. Phosphorous is reduced to P_4 gas together with carbon dioxide and dust. After flue gas treatment, phosphorous was condensed and stored in a water bath with a purity of over 99.9% (Tervahauta et al., 2014). What is more, phosphorous could be vaporized and recovered as a pure phosphorous element using the InduCarb reactor, with a temperature of between 1300 and 1600 °C (Schonberg et al., 2014). Phosphorous and CO leave the reactor in the gas phase and are further treated: CO could be used for energy production and phosphorous was recovered in the form of iron – P alloy. Based on the above, the advantages and disadvantages of each technology together with the identification of potential compounds that might hinder its application were detailed in Table 3.

3.3.2 TRL assessment

From the literature review, the occurrence of each technology in literature was divided into lab, pilot and full scale, and the result is shown in Figure 2. TRL ranges and scores were then calculated and are summarized in Table 4.

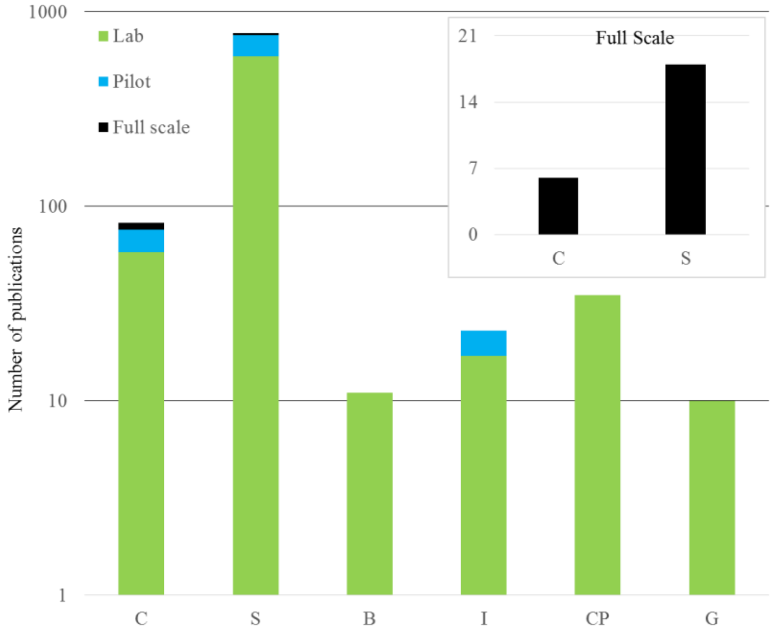

Figure 2: Number of lab, pilot and full-scale applications of key phosphorous recovery technologies (symbols are defined in Table 3)

Despite a large number of technologies that were available at lab and pilot scale levels, these technologies required a significant financial undertaking to commercialise (James, 2017). As defined by James (2017), the percentage of research and development cost for each TRL score was the amount spent thus far on development to the percentage of the total estimated cost to complete a project development loop. For example, a TRL 1 spent 1 - 4% of total cost, TRL 4 spent 12 - 26% of total cost, while TRL 9 spent 100%.

Table 4: TRLs for different phosphorous recovery technologies

	TRL range	TRL score	Remarks
Composting	7 to 9	9	Excellent technological ‘knowhow’ and large number of applications
Struvite Crystallization	7 to 9	9	Some technical ‘knowhow’, but with a large number of full scale applications
Biomineralization	1 to 3	1	A few studies on reaction mechanisms
Incineration	4 to 6	6	A few pilot scale plants in operation, good technical ‘knowhow’
Calcium P	1 to 3	3	Concept proven with pilot operations
Gasification	4 to 6	5	A proven concept and good technical knowhow

As can be seen in Table 4, composting and struvite crystallization were the only two technologies that have currently being validated and implemented in industry, indicating that there are much less research and development costs for future application. In comparison, calcium phosphate, gasification and incineration are well understood and are able to be implemented given sufficient technology development. However, reaction mechanisms and potential influential factors for biomineralization are not well understood yet. Therefore, lack of mature technologies, as well as the cost of transitioning them into feasible solutions are barriers for wide spread commercialisation. From a government policy point of view, such TRL transition can be aided by grants for academic and industrial collaborative projects that specifically transform phosphorous recovery technology currently in pilot scale for commercialization.

3.4 Step 4: Economic analysis

As discussed in Section 3.3, struvite crystallization is a mature technology for phosphorous recovery from aqueous solution, and composting is currently available for phosphorous recovery from solid waste. As this paper used a wastewater treatment plant as a case study, from this point onwards, only struvite crystallization will be discussed. With details listed in Table 5, a positive discounted value of future cash flow of $1.7 million USD is calculated for the base case. As long as the capital cost of a struvite crystallization unit is less than 1.7 million, the process is profitable. However, wastewater composition, plant operation conditions and market environment vary over time. It is thus important to understand key variables affect the PV calculation using sensitivity analysis. This allows a robust understanding of the overall profitability of phosphorous recovery under market, economic and operating conditions that can be expected in reality.

Table 5: Process variables considered in case study

	Case Study		**Sensitivity Analysis**			**Remarks**
	Value	**Unit**	**Symbol**	**-1**	**1**	
P Concentration	5	mg/L	A	4	10	Inorganic PO_4^{3-} in wastewater
P Enrichment Efficiency	60	%	B	50	90	An index of total P entering the struvite recovery unit
Struvite Recovery Efficiency	60	%	C	50	100	An index of production and collection efficiency during struvite recovery
Mg/Ca ratio	1.1	-	D	1.1	1.8	Additional Mg is required when Ca concentration increases
Struvite Price	740	$	E	300	800	Price of struvite as fertilizer
Magnesium Price	400	$	F	300	1000	Price of magnesium sources per ton, varying between $MgCl_2$, $MgCO_3$, $Mg(OH)_2$
Alkali Price	200	$	G	150	500	Alkali used to improve pH for struvite recovery, varying between NaOH, $Mg(OH)_2$
Discount Rate	15	%	H	0.05	0.25	The percentage devaluation of future revenue streams
Volume	550000	m^3/day	-	-	-	Assume no change over time
Influent pH	6.5	-	-	-	-	Not used in DoE as not sensitive
P Enrichment Factor	30	-	-	-	-	Not used in DoE as not sensitive
Maintenance Cost	100000	$	-	-	-	Fixed as estimated for 0.25 Full time Equivalent person plus maintenance
Payback Period	10		-	-	-	A payback period of ten-years is used
Electricity Usage	0.15	Kwh	-	-	-	Per ton of wastewater processed, not used as it is insignificant
Electricity Price	0.2	$	-	-	-	Not used as it is insignificant

3.5 Step 5: Sensitivity Analysis

DoE was conducted in Design Expert software (8.0.7) for sensitivity analysis. The ANOVA analysis (shown in Table 5, where only significant terms are reported) give an F-value of 105.4, meaning that the model employed is significant. There is only a 0.01% chance that 'model F–values' this large would occur due to noise. The R^2 is a measure of the goodness of fit of the model used to explain the data. The calculated R^2 is 0.93 and adjusted R^2 is 0.94, respectively.

Adequate precision is a signal to noise ratio that compares the range of the predicted values at the design points to the average prediction error. Ratios higher than 4 indicate adequate model discrimination (Ye, 2010). In the developed model, a ratio of 63.0 implies the model could be used to navigate the designed space.

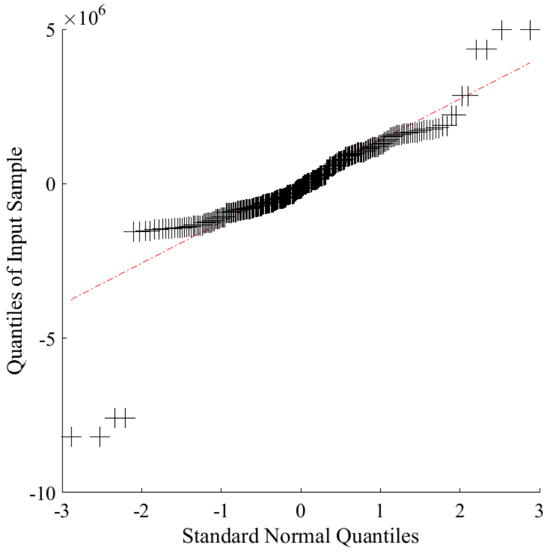

Figure 3: quantile-quantile plot of designed conditions

A quantile-quantile plot of quantiles displays the sample data, x, versus the theoretical quantiles from a normal distribution. The plot appears linear if the distribution of x is normal. A quantile-quantile (Q-Q) plot is shown in Figure 3, where the data lies approximately in a straight line, indicating that the underlying distribution is normal. Thus, the model is able to represent the experimental data.

The present value (PV) of future cash flows of 256 scenarios (shown in the appendix) for sensitivity analysis is plotted in Figure 4. As can be seen, a positive NPV was obtained after run 187, where most scenarios (72%) gave a negative NPV for the different process conditions. However, most negative PV scenarios are close to breakeven, which can be profitable or break-even if financial assistance is extended by policymakers. By considering the fact that phosphorous recovery reduces the nutrient load in downstream units, and reduces pipeline fouling in large wastewater treatment facilities (Huang et al., 2019), phosphorous recovery is still recommended.

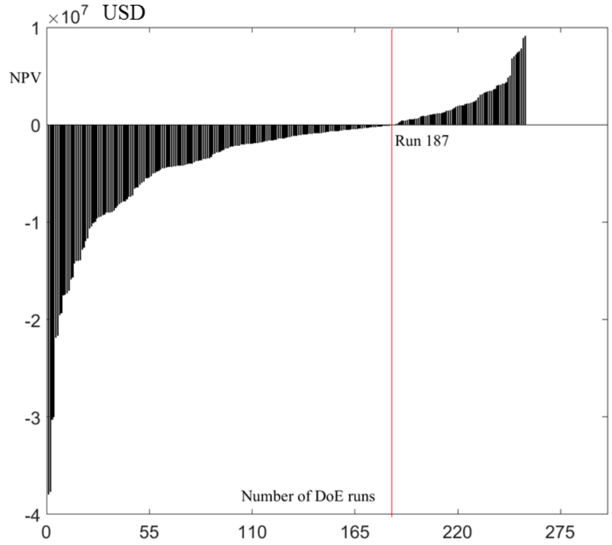

Figure 4: **N**PV of the Future Cash Flows

Details on how the above-mentioned factors (listed in Table 5) contribute to variations in PV was shown in Table 6. As can be seen, market variables such as magnesium and struvite price account for 42.5% and 13.5% of the total variation in PV. That is to say, more than 60% variation in PV is from market variation, which is out of an engineer's/scientist's control. Struvite recovery efficiency, PO_4^{3-} enrichment efficiency and magnesium dosage ratio have an impact of 16.3%, 12.0% and 8.5% respectively.

Table 6: Contribution of variables to PV change

Variable type	**Variables**	**Contribution to PV (%)**
Technical	C-Struvite recovery P efficiency	16.3
	B-Enrichment efficiency	12.0
	D-Mg dosage ratio	8.5
	A-P Concentration	3.0
Market	F-Magnesium price	42.5
	E-Struvite price	13.5
	H-Discount Rate	4.2
	G-Cost of NaOH	0.2

As a result of this analysis. It may be concluded that, future technology development on improving the struvite recovery efficiency may be more valuable than enriching phosphorus concentration in the influent. This is contradictory to previous research (Li et al., 2016), most of which reported that influent PO_4^{3-} concentration affects the process performance significantly. This might be because of the ignorance of market and process efficiency. From the current study, the total amount of phosphorous rather than the concentration in the influent is more important during the implementation of a phosphorous recovery technology.

As phosphorous recovery via struvite crystallization produces a CO_2 abatement of about 100 kg/T less than traditional phosphate rock extraction (Yetilmezsoy et al., 2017), with a cost of CO_2 emissions is between 20 – 120 USD a tonne, an additional environmental profit of 2-12 USD could be generated per each tonne of struvite recovered. This gives a 4,000-24,000 USD in total for the wastewater treatment plant investigated, without considering extra packaging and transportation cost in traditional phosphate rock extraction processes. Although this is a minor amount, it can shift some scenarios to positive PV projects, which means they can be operated without making economic losses.

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It is also important to note that this analysis has not considered the investment necessary for building a phosphorous recovery plant, which would make a large number of scenarios explored unprofitable in a strict economic sense. This can be somewhat blanketed by preferential borrowing conditions for investors in phosphorous recovery endorsed by the governments or tax credits offered for Waste water treatment plant operators for investing in P recovery units.

4.0 Implications

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Morocco, China, Algeria and the USA account for almost 85% of the world's phosphate rock reserves (Li et al., 2018), therefore, large phosphorous consumers, such as Japan and EU, may adopt preferential policies to make phosphorous recovery economically viable by increased phosphate import tariffs or provide phosphorous recovery subsidies. At the same time, specific funding transferring current pilot or lab scale phosphorous recovery technologies to full scale processes should be introduced. This in turn will provide a better technology choice for future phosphorous recovery projects. What is more, a combination of phosphorous recovery with other pre-treatment or post-treatment technologies is recommended, which helps to increase the process efficiency (for example, increase the struvite recovery efficiency or PO_4^{3-} enrichment efficiency), add extra value and reduce the capital and operational costs. Due to the lack of data, only struvite precipitation was used to demonstrate the usage of the proposed framework. Current barriers based on this process for efficient phosphorous recovery are: Based on the above discussion, current barriers for the commercialization of phosphors recovery are:

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1) Only struvite crystallization and composting are ready for commercialization, while other technologies require significant investment in research and development;

2) Government awareness of the phosphorus resource crisis and role of phosphorous in water quality is insufficient;
3) The recovery process is sensitive to influent composition, making it difficult to control and making the process unprofitable in a strict economic sense;
4) Market price variation significantly affects the process economics, while the current low value added product did not increase the process income significantly.

5. Conclusions

An enhanced methodology was proposed to identify barriers to the commercialisation of current phosphorous recovery technologies. The economic payback of P recovery in the current state of affairs is weak, while only struvite crystallization and composting are currently at high technology maturity that makes an industrial implementation possible. Sensitivity analysis illustrated that the phosphorus concentration in a given stream is only one of the many factors that dictate the profitability of a given implementation. Struvite crystallization, as currently the only mature process for phosphorous recovery from aqueous streams, is marginally non-profitable, where both the market (sales and purchasing cost) and operating conditions have a significant impact on its PV. Government subsidies to P recovery units or imposing taxes on extracted phosphorous is recommended to overcome the current gap. In terms of struvite crystallization, further research on process efficiency improvement (e.g. struvite recovery efficiency, PO_4^{3-} enrichment efficiency and magnesium dosage ratio) is required to increase its overall profitability. The proposed methodology could also be extended to identify barriers in other resource recovery technologies.

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Appendix: PV result for sensitivity analysis

Run number	P Concentration (mg/L)	P Enrichment Efficiency (%)	Struvite Recovery Efficiency (%)	Mg/Ca ratio	Struvite (USD)	Magnesium (USD)	Alkali (USD)	Discount Rate (%)	NPV (USD)
1	10	90	100	1.8	300	1000	500	0.05	-$37,929,162.0
2	10	90	100	1.8	300	1000	150	0.05	-$37,691,332.5
3	10	90	100	1.8	800	1000	500	0.05	-$30,284,644.4
4	10	90	100	1.8	800	1000	150	0.05	-$30,046,815.0
5	10	90	100	1.1	300	1000	500	0.05	-$21,875,675.1
6	10	90	100	1.1	300	1000	150	0.05	-$21,637,845.6
7	10	50	100	1.8	300	1000	500	0.05	-$19,582,319.8
8	10	50	100	1.8	300	1000	150	0.05	-$19,344,490.3
9	10	90	100	1.8	300	1000	500	0.25	-$17,538,312.1
10	10	90	100	1.8	300	1000	150	0.25	-$17,428,340.6
11	10	90	50	1.8	300	1000	500	0.05	-$17,288,964.5
12	10	90	50	1.8	300	1000	150	0.05	-$17,051,135.1
13	4	90	100	1.8	300	1000	500	0.05	-$15,912,951.3
14	4	90	100	1.8	300	1000	150	0.05	-$15,675,121.9
15	10	90	100	1.1	800	1000	500	0.05	-$14,231,157.5
16	10	90	100	1.8	800	1000	500	0.25	-$14,003,513.8
17	10	90	100	1.1	800	1000	150	0.05	-$13,993,328.0
18	10	90	100	1.8	800	1000	150	0.25	-$13,893,542.3
19	4	90	100	1.8	800	1000	500	0.05	-$12,855,144.3
20	4	90	100	1.8	800	1000	150	0.05	-$12,617,314.9
21	10	50	100	1.8	800	1000	500	0.05	-$11,937,802.2
22	10	50	100	1.8	800	1000	150	0.05	-$11,699,972.8
23	10	50	100	1.1	300	1000	500	0.05	-$10,663,715.9
24	10	50	100	1.1	300	1000	150	0.05	-$10,425,886.5
25	10	90	100	1.1	300	1000	500	0.25	-$10,115,235.8
26	10	90	100	1.1	300	1000	150	0.25	-$10,005,264.3
27	10	90	50	1.8	800	1000	500	0.05	-$9,644,446.9

28	4	90	100	1.1	300	1000	500	0.05	-$9,491,556.6
29	10	90	50	1.8	800	1000	150	0.05	-$9,406,617.5
30	10	90	50	1.1	300	1000	500	0.05	-$9,262,221.0
31	4	90	100	1.1	300	1000	150	0.05	-$9,253,727.1
32	10	50	100	1.8	300	1000	500	0.25	-$9,054,796.3
33	10	90	100	1.8	300	300	500	0.05	-$9,032,885.5
34	10	90	50	1.1	300	1000	150	0.05	-$9,024,391.6
35	10	50	100	1.8	300	1000	150	0.25	-$8,944,824.8
36	10	90	100	1.8	300	300	150	0.05	-$8,795,056.1
37	4	50	100	1.8	300	1000	500	0.05	-$8,574,214.5
38	4	50	100	1.8	300	1000	150	0.05	-$8,336,385.0
39	10	50	50	1.8	300	1000	500	0.05	-$8,115,543.4
40	10	90	50	1.8	300	1000	500	0.25	-$7,994,356.8
41	10	90	50	1.8	300	1000	150	0.25	-$7,884,385.3
42	10	50	50	1.8	300	1000	150	0.05	-$7,877,714.0
43	4	90	50	1.8	300	1000	500	0.05	-$7,656,872.4
44	4	90	50	1.8	300	1000	150	0.05	-$7,419,042.9
45	4	90	100	1.8	300	1000	500	0.25	-$7,358,093.1
46	4	90	100	1.8	300	1000	150	0.25	-$7,248,121.6
47	10	90	100	1.1	800	1000	500	0.25	-$6,580,437.5
48	10	90	100	1.1	800	1000	150	0.25	-$6,470,466.0
49	4	90	100	1.1	800	1000	500	0.05	-$6,433,749.5
50	4	90	100	1.1	800	1000	150	0.05	-$6,195,920.1
51	4	90	100	1.8	800	1000	500	0.25	-$5,944,173.8
52	4	90	100	1.8	800	1000	150	0.25	-$5,834,202.3
53	10	50	100	1.8	800	1000	500	0.25	-$5,519,998.1
54	4	50	100	1.8	800	1000	500	0.05	-$5,516,407.4
55	10	50	100	1.8	800	1000	150	0.25	-$5,410,026.6
56	4	50	100	1.8	800	1000	150	0.05	-$5,278,578.0
57	4	50	100	1.1	300	1000	500	0.05	-$5,006,772.9
58	10	50	100	1.1	300	1000	500	0.25	-$4,930,865.0
59	10	50	100	1.1	300	1000	150	0.25	-$4,820,893.5
60	4	50	100	1.1	300	1000	150	0.05	-$4,768,943.5
61	4	90	50	1.8	800	1000	500	0.05	-$4,599,065.3
62	10	90	50	1.8	800	1000	500	0.25	-$4,459,558.6
63	4	90	50	1.1	300	1000	500	0.05	-$4,446,175.0
64	4	90	100	1.1	300	1000	500	0.25	-$4,388,862.6
65	4	90	50	1.8	800	1000	150	0.05	-$4,361,235.9
66	4	90	100	1.8	300	300	500	0.05	-$4,354,440.8
67	10	90	50	1.8	800	1000	150	0.25	-$4,349,587.1
68	10	90	50	1.1	300	1000	500	0.25	-$4,282,818.7
69	4	90	100	1.1	300	1000	150	0.25	-$4,278,891.1
70	10	90	100	1.1	300	300	500	0.05	-$4,216,839.4
71	4	90	50	1.1	300	1000	150	0.05	-$4,208,345.5
72	10	90	100	1.8	300	300	500	0.25	-$4,176,774.7
73	10	90	50	1.1	300	1000	150	0.25	-$4,172,847.2
74	4	90	100	1.8	300	300	150	0.05	-$4,116,611.3
75	10	90	100	1.8	300	300	150	0.25	-$4,066,803.2

76	4	50	50	1.8	300	1000	500	0.05	-$3,987,503.9
77	10	90	100	1.1	300	300	150	0.05	-$3,979,010.0
78	4	50	100	1.8	300	1000	500	0.25	-$3,964,686.8
79	4	50	100	1.8	300	1000	150	0.25	-$3,854,715.3
80	10	50	50	1.8	300	1000	500	0.25	-$3,752,598.9
81	4	50	50	1.8	300	1000	150	0.05	-$3,749,674.5
82	10	50	50	1.1	300	1000	500	0.05	-$3,656,241.5
83	10	50	50	1.8	300	1000	150	0.25	-$3,642,627.4
84	4	90	50	1.8	300	1000	500	0.25	-$3,540,511.0
85	10	50	100	1.8	300	300	500	0.05	-$3,528,832.9
86	4	90	50	1.8	300	1000	150	0.25	-$3,430,539.5
87	10	50	50	1.1	300	1000	150	0.05	-$3,418,412.1
88	10	50	100	1.8	300	300	150	0.05	-$3,291,003.4
89	10	50	100	1.1	800	1000	500	0.05	-$3,019,198.4
90	4	90	100	1.1	800	1000	500	0.25	-$2,974,943.3
91	4	90	100	1.1	800	1000	150	0.25	-$2,864,971.8
92	10	90	50	1.8	300	300	500	0.05	-$2,840,826.3
93	10	50	100	1.1	800	1000	150	0.05	-$2,781,368.9
94	10	90	50	1.8	300	300	150	0.05	-$2,602,996.8
95	4	50	100	1.8	800	1000	500	0.25	-$2,550,767.5
96	4	50	100	1.8	800	1000	150	0.25	-$2,440,796.0
97	4	90	100	1.1	300	300	500	0.05	-$2,428,022.3
98	4	50	100	1.1	300	1000	500	0.25	-$2,315,114.3
99	4	50	100	1.1	300	1000	150	0.25	-$2,205,142.8
100	4	50	50	1.1	300	1000	500	0.05	-$2,203,783.1
101	4	90	100	1.1	300	300	150	0.05	-$2,190,192.9
102	4	50	100	1.8	300	300	500	0.05	-$2,152,819.7
103	4	90	50	1.8	800	1000	500	0.25	-$2,126,591.7
104	4	90	50	1.1	300	1000	500	0.25	-$2,055,895.8
105	4	90	50	1.8	800	1000	150	0.25	-$2,016,620.2
106	4	90	100	1.8	300	300	500	0.25	-$2,013,478.2
107	4	50	50	1.1	300	1000	150	0.05	-$1,965,953.7
108	10	90	100	1.1	300	300	500	0.25	-$1,949,851.8
109	4	50	100	1.1	800	1000	500	0.05	-$1,948,965.9
110	4	90	50	1.1	300	1000	150	0.25	-$1,945,924.3
111	4	50	100	1.8	300	300	150	0.05	-$1,914,990.3
112	4	90	100	1.8	300	300	150	0.25	-$1,903,506.7
113	4	90	50	1.8	300	300	500	0.05	-$1,877,617.1
114	4	50	50	1.8	300	1000	500	0.25	-$1,843,807.9
115	10	90	100	1.1	300	300	150	0.25	-$1,839,880.3
116	4	50	50	1.8	300	1000	150	0.25	-$1,733,836.4
117	4	50	100	1.1	800	1000	150	0.05	-$1,711,136.5
118	10	50	50	1.1	300	1000	500	0.25	-$1,690,633.3
119	4	90	50	1.8	300	300	150	0.05	-$1,639,787.6
120	10	50	100	1.8	300	300	500	0.25	-$1,631,720.0
121	10	90	50	1.1	800	1000	500	0.05	-$1,617,703.5
122	10	50	50	1.1	300	1000	150	0.25	-$1,580,661.8
123	10	50	100	1.8	300	300	150	0.25	-$1,521,748.5

124	10	50	100	1.1	800	1000	500	0.25	-$1,396,066.8
125	4	90	50	1.1	800	1000	500	0.05	-$1,388,367.9
126	10	90	100	1.8	800	300	500	0.05	-$1,388,367.9
127	10	90	50	1.1	800	1000	150	0.05	-$1,379,874.0
128	10	90	50	1.8	300	300	500	0.25	-$1,313,588.2
129	4	90	100	1.8	800	300	500	0.05	-$1,296,633.7
130	10	50	100	1.1	800	1000	150	0.25	-$1,286,095.3
131	10	90	50	1.8	300	300	150	0.25	-$1,203,616.7
132	4	90	50	1.1	800	1000	150	0.05	-$1,150,538.5
133	10	90	100	1.8	800	300	150	0.05	-$1,150,538.5
134	4	90	100	1.1	300	300	500	0.25	-$1,122,709.0
135	4	50	100	1.1	300	300	500	0.05	-$1,082,587.2
136	4	90	100	1.8	800	300	150	0.05	-$1,058,804.3
137	4	50	50	1.1	300	1000	500	0.25	-$1,019,021.6
138	4	90	100	1.1	300	300	150	0.25	-$1,012,737.5
139	4	50	100	1.8	300	300	500	0.25	-$995,456.3
140	4	50	50	1.8	800	1000	500	0.05	-$929,696.9
141	4	90	50	1.1	300	300	500	0.05	-$914,407.9
142	4	50	50	1.1	300	1000	150	0.25	-$909,050.1
143	4	50	100	1.1	800	1000	500	0.25	-$901,195.0
144	4	50	100	1.8	300	300	150	0.25	-$885,484.8
145	4	90	50	1.8	300	300	500	0.25	-$868,203.6
146	10	50	100	1.1	300	300	500	0.05	-$853,251.7
147	4	50	100	1.1	300	300	150	0.05	-$844,757.8
148	4	50	100	1.1	800	1000	150	0.25	-$791,223.5
149	4	50	50	1.8	300	300	500	0.05	-$776,806.5
150	4	90	50	1.8	300	300	150	0.25	-$758,232.1
151	10	90	50	1.1	800	1000	500	0.25	-$748,020.4
152	4	50	50	1.8	800	1000	150	0.05	-$691,867.4
153	4	90	50	1.1	300	300	150	0.05	-$676,578.4
154	4	90	50	1.1	800	1000	500	0.25	-$641,976.5
155	10	90	100	1.8	800	300	500	0.25	-$641,976.5
156	10	90	50	1.1	800	1000	150	0.25	-$638,048.9
157	10	50	100	1.1	300	300	150	0.05	-$615,422.3
158	4	90	100	1.8	800	300	500	0.25	-$599,558.9
159	4	50	50	1.8	300	300	150	0.05	-$538,977.1
160	4	90	50	1.1	800	1000	150	0.25	-$532,005.0
161	10	90	100	1.8	800	300	150	0.25	-$532,005.0
162	4	50	100	1.1	300	300	500	0.25	-$500,584.6
163	4	90	100	1.8	800	300	150	0.25	-$489,587.4
164	10	50	50	1.8	800	1000	500	0.05	-$471,025.8
165	10	90	50	1.1	300	300	500	0.05	-$432,803.2
166	4	50	50	1.8	800	1000	500	0.25	-$429,888.6
167	4	90	50	1.1	300	300	500	0.25	-$422,819.0
168	10	50	100	1.1	300	300	500	0.25	-$394,540.6
169	4	50	100	1.1	300	300	150	0.25	-$390,613.1
170	4	50	50	1.8	300	300	500	0.25	-$359,192.6
171	4	50	50	1.8	800	1000	150	0.25	-$319,917.1

172	4	90	50	1.1	300	300	150	0.25	-$312,847.5
173	10	50	100	1.1	300	300	150	0.25	-$284,569.1
174	4	50	50	1.8	300	300	150	0.25	-$249,221.1
175	4	50	50	1.1	300	300	500	0.05	-$241,690.3
176	10	50	50	1.8	800	1000	150	0.05	-$233,196.4
177	10	50	50	1.8	800	1000	500	0.25	-$217,800.7
178	10	90	50	1.1	300	300	500	0.25	-$200,126.7
179	10	90	50	1.1	300	300	150	0.05	-$194,973.8
180	4	50	50	1.1	300	300	500	0.25	-$111,756.8
181	10	50	50	1.8	800	1000	150	0.25	-$107,829.2
182	10	90	50	1.1	300	300	150	0.25	-$90,155.2
183	10	50	50	1.8	300	300	500	0.05	-$88,800.0
184	10	50	50	1.8	300	300	500	0.25	-$41,060.8
185	4	50	50	1.1	300	300	150	0.05	-$3,860.9
186	4	50	50	1.1	300	300	150	0.25	-$1,785.3
187	10	50	50	1.8	300	300	150	0.25	$68,910.7
188	10	50	50	1.8	300	300	150	0.05	$149,029.5
189	4	90	100	1.1	800	300	500	0.25	$291,210.2
190	4	50	50	1.1	800	1000	500	0.25	$394,897.7
191	4	90	100	1.1	800	300	150	0.25	$401,181.7
192	4	50	100	1.8	800	300	500	0.25	$418,463.0
193	4	50	50	1.1	800	1000	150	0.25	$504,869.2
194	4	50	100	1.8	800	300	150	0.25	$528,434.5
195	4	90	50	1.8	800	300	500	0.25	$545,715.7
196	10	50	50	1.1	300	300	500	0.25	$577,528.9
197	4	90	100	1.1	800	300	500	0.05	$629,784.7
198	4	90	50	1.8	800	300	150	0.25	$655,687.2
199	10	50	50	1.1	300	300	150	0.25	$687,500.4
200	4	50	50	1.1	800	1000	500	0.05	$854,023.9
201	4	90	100	1.1	800	300	150	0.05	$867,614.1
202	4	50	100	1.8	800	300	500	0.05	$904,987.3
203	4	50	100	1.1	800	300	500	0.25	$913,334.7
204	4	90	50	1.1	800	300	500	0.25	$991,100.3
205	4	50	100	1.1	800	300	150	0.25	$1,023,306.2
206	4	50	50	1.8	800	300	500	0.25	$1,054,726.7
207	4	50	50	1.1	800	1000	150	0.05	$1,091,853.3
208	4	90	50	1.1	800	300	150	0.25	$1,101,071.8
209	4	50	100	1.8	800	300	150	0.05	$1,142,816.8
210	4	50	50	1.8	800	300	150	0.25	$1,164,698.2
211	4	90	50	1.8	800	300	500	0.05	$1,180,190.0
212	10	50	50	1.1	300	300	500	0.05	$1,248,990.6
213	4	50	50	1.1	800	300	500	0.25	$1,302,162.5
214	4	50	50	1.1	800	300	150	0.25	$1,412,134.0
215	4	90	50	1.8	800	300	150	0.05	$1,418,019.4
216	10	50	50	1.1	300	300	150	0.05	$1,486,820.1
217	10	90	100	1.1	800	300	500	0.25	$1,584,946.4
218	10	90	100	1.1	800	300	150	0.25	$1,694,917.9
219	10	50	50	1.1	800	1000	500	0.25	$1,844,164.9

220	10	50	100	1.8	800	300	500	0.25	$1,903,078.2
221	10	50	50	1.1	800	1000	150	0.25	$1,954,136.4
222	4	50	100	1.1	800	300	500	0.05	$1,975,219.8
223	10	50	100	1.8	800	300	150	0.25	$2,013,049.7
224	4	90	50	1.1	800	300	500	0.05	$2,143,399.2
225	4	50	100	1.1	800	300	150	0.05	$2,213,049.2
226	10	90	50	1.8	800	300	500	0.25	$2,221,210.1
227	4	50	50	1.8	800	300	500	0.05	$2,281,000.5
228	10	90	50	1.8	800	300	150	0.25	$2,331,181.6
229	4	90	50	1.1	800	300	150	0.05	$2,381,228.6
230	4	50	50	1.8	800	300	150	0.05	$2,518,829.9
231	4	50	50	1.1	800	300	500	0.05	$2,816,116.7
232	4	50	50	1.1	800	300	150	0.05	$3,053,946.2
233	10	50	100	1.1	800	300	500	0.25	$3,140,257.6
234	10	50	100	1.1	800	300	150	0.25	$3,250,229.1
235	10	90	50	1.1	800	300	500	0.25	$3,334,671.5
236	10	90	100	1.1	800	300	500	0.05	$3,427,678.1
237	10	90	50	1.1	800	300	150	0.25	$3,444,643.0
238	10	50	50	1.8	800	300	500	0.25	$3,493,737.5
239	10	50	50	1.8	800	300	150	0.25	$3,603,709.0
240	10	90	100	1.1	800	300	150	0.05	$3,665,507.6
241	10	50	50	1.1	800	1000	500	0.05	$3,988,276.1
242	10	50	50	1.1	800	300	500	0.25	$4,112,327.1
243	10	50	100	1.8	800	300	500	0.05	$4,115,684.7
244	10	50	50	1.1	800	300	150	0.25	$4,222,298.6
245	10	50	50	1.1	800	1000	150	0.05	$4,226,105.5
246	10	50	100	1.8	800	300	150	0.05	$4,353,514.2
247	10	90	50	1.8	800	300	500	0.05	$4,803,691.3
248	10	90	50	1.8	800	300	150	0.05	$5,041,520.7
249	10	50	100	1.1	800	300	500	0.05	$6,791,265.9
250	10	50	100	1.1	800	300	150	0.05	$7,029,095.3
251	10	90	50	1.1	800	300	500	0.05	$7,211,714.3
252	10	90	50	1.1	800	300	150	0.05	$7,449,543.8
253	10	50	50	1.8	800	300	500	0.05	$7,555,717.6
254	10	50	50	1.8	800	300	150	0.05	$7,793,547.1
255	10	50	50	1.1	800	300	500	0.05	$8,893,508.2
256	10	50	50	1.1	800	300	150	0.05	$9,131,337.6