The principles of project: Inorganic waste of chemical industry - technology foresight

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Introduction

"Technology foresight", a special prognostic procedure employing various analytical methods, is widely applied in developed countries. It has been adopted in the European Union as a recommended approach to thinking and acting with regard to the future. A lot of foresight projects have been implemented in Poland, including Foresight Polska 2020 [1]; however, none of them has sufficiently dealt with the issue of inorganic chemical industry waste. The inorganic industry sector in Poland is well-developed, but it requires some change and transformations, since apart from creating a significant portion of the GDP, it is perceived as noxious for the environment and for human health. On the other hand, it is indispensable for efficient functioning of other branches of the economy. The inorganic chemical industry in Poland requires considerable investment – the foreign trade deficit in chemicals trade amounted to 9 billion euro in 2008 [2]. This provides great opportunities for implementation of the results of development forecasts and new technological solutions.

A consortium consisting of the Inorganic Chemistry Section "IChN" in Gliwice of the Artificial Fertilisers Institute, Institute of Environment Protection and the Progress&Business Foundation has been awarded a grant from the European Regional Development Fund for implementation of the programme named "Inorganic waste of chemical industry – technology foresight" within the Operational Programme "Innovative Economy". The project to be implemented from 01.01.2010 to 31.12.2011 is to develop scenarios for inorganic chemistry, which will help to manage waste of inorganic chemical industry and to set new trends for new technologies in manufacturing inorganic products in Poland by 2030. The problem analysis, developing the research model and preparation of development scenarios, will involve using the state-of-the art analytical and research methods, typical of the foresight process: methods of multicriteria analysis, discrete event systems, quantitative methods of *cross-impact analysis* based on the control theory methods and methods of knowledge presentation [3].

From the point of view of environmental and economic policy, waste is an unusable product of economic and social processes and, as such, requires management in a manner protecting human and environmental safety from hazards created by its presence in the environment and in the immediate surroundings of people. Such management requires investments which are inseparable cost components of product manufacturing. Therefore, it would be ideal to employ such processes which do not produce waste. However, there are no such processes in the economic practice, but it is logical to recognise reduction of the amount of waste as a priority in waste management. This task largely goes beyond the issues of waste management and enters the domain of production process and service provision design. Its implementation requires that industry and the service sector employ environment-friendly technologies [4].

The work performed by the experts engaged in the National Foresight Programme "Poland 2020", has produced development scenarios for Poland, but also a list of recommended technologies, the accumulated scientific potential and intellectual capital of which creates opportunities of implementations that lead to the development of competitive or niche branches of economy. Five technologies have been recommended for waste management:

- Advanced, waste-free material technologies and biodegradable engineering materials for industry, transport and power engineering, with an environment-friendly, closed life cycle;
- Environment-friendly chemical products and technologies of processing fossil materials, biomass and waste and turning them into commonly used chemicals and fuels;
- New generation of technologies of effective acquisition and use of domestic resources of fossil raw materials, at the same time ensuring environmental safety;
- Low-waste and waste-free production technologies and industrial methods of waste utilisation and hazardous waste neutralisation;
- New technologies of restricting the environmental occurrence of substances regarded as particularly hazardous [5];

Inorganic chemical industry produces industrial waste which is noxious to the environment. According to the National Waste Management Plan 2010 [6], waste from production, preparation, trade and use of products of inorganic chemical industry is produced mainly by plants manufacturing mineral fertilisers, soda, pigments and other chemical plants, as well as steelworks and copper smelting plants. Improvement of domestic waste management, both in terms of reducing its production output by changing and optimising the existing technologies, and the technologies of waste utilisation, is the long-term objective of the Project. This is what the development scenarios and reports generated by the Project should be used for. Polish chemical companies (CIECH S.A., Siarkopol Tarnobrzeg, Luvena S.A. and Chemia Wizów Sp. z o.o.) and organisations, such as Polish Chamber of Chemical Industry, as well as environmental organisations submit letters of intent attached to applications for research funding, thereby confirming the pertinence of the scope of research of the Project in question and declaring their willingness to implement the solutions developed by it in industry.

State of knowledge and identification of key research needs

A strategy of handling waste in the European Union countries is laid down in a document issued by the European Commission [7]. Reduction of waste and intensification of recovery lower the effect of non-renewable resources consumption on the environment, which plays a major role in sustainable development. Waste management is more and more often evaluated with the use of the Life Cycle Analysis (LCA) [8]. The analysis involves the assessment of the impact of the product under analysis (material or object) on the environment throughout its life cycle – including its production, use and post-utilisation management. The consecutive stages of the LCA are: (1) identification and quantitative analysis of the impact on the environment of the product under evaluation (i.e. consumption of materials and energy, emission of pollution, waste released to the environment), (2) evaluation of potential effects of such impact, (3) estimation of the available ways of reducing such impact. The analysis, which covers the entire period of production and use of the product and managing waste formed from it afterwards, allows for comparison of the amount of energy and materials spent on manufacturing the product and its negative impact on the environment. Determination of the total impact of a product on the environment provides grounds for finding the cost of environment protection associated with production and use of substances and prod-

ucts; this in turn is the base for determination of the necessary investment in environment protection, which arise from socially accepted level of environmental risk. The choice of the way of waste management depends on the local conditions and its aim is to avoid a negative impact of the parts of the environment already affected by other types of activities [9]. The sequence of waste management actions, if waste production could not be avoided, is as follows: recovery, material recycling and energy recovery, neutralisation. A lot of waste is subjected to recycling processes (e.g. metals, paper, plastics). This is basically impossible for inorganic waste – it is useless for recycling. This concerns, for example, phosphogypsum in artificial fertiliser manufacturing or calcium chloride in soda production industry. If that is the case, such options as a change of production process, raw material arrangement, replacing the product with another need to be considered, or, as a final resort, reduction of the product quantity. Waste-related regulations of the EU provide for introducing criteria for selected recovery processes and applying the provisions of the EC regulation to combat fictional waste recovery [10]. In its resolution of 20 April 2004, the European Parliament called for the Commission to consider expanding the Directive of the Council 96/61/EC of 24 September 1996 on integrated prevention of pollution and its control to the entire waste sector [11]. The European Parliament also asked the Commission to clearly distinguish between recovery and neutralisation of waste and to explain the difference between waste and substances which are not regarded as such. The provisions of Directive 96/61/EC are implemented in the Polish legislation by the Environment Protection Act [12]. Art. 16(2) of the Directive obligates the European Commission to arrange for information exchange on the best available technologies (BAT) within the applied technology and monitoring. Such information is published as BREF documents issued by the European Commission. Directorate General - JRC Joint Research Centre - Institute for Prospective Technologies. The concept of BAT – the Best Available Technology – should be understood to denote the most effective and state-of-the-art technology solutions, useful for prevention of release of pollution to the environment or, if this proved impossible, for reduction of such release and lowering its impact on the environment. "Technology" is understood to denote both the technological process and technological (apparatus, equipment, fittings of buildings and constructions, their servicing and maintenance) and organisational solutions. "Availability" means the economic conditions of application (costs) and possibility of applying the solution with the existing infrastructure. The IPPC directive (appendix IV) lays down the following criteria of technology evaluation in unit operations and procedures:

- application of low-waste technology;
- using less hazardous substances;
- providing for recovery and recycling of substances and waste produced in the process;
- indicating comparable processed, devices or procedures, used on an industrial scale;
- progress in technology and knowledge;
- types, effects and size of emissions from the process;
- results of examination of new and existing systems;
- time needed to implement the best available technology;
- consumption and types of raw materials (including water) and energy efficiency of the system;
- the needs in terms of prevention or reduction of release to the environment and environmental risks;
- the needs in terms of preventing failures and their impact on the environment;
- information published by the European Commission in compliance with the requirements of the directive (BAT, system monitoring, associated technological progress);

The strategy adopted in the IPPC directive relates the obligation to reduce the amount and noxiousness of waste to the environment to industrial systems which manufacture products and the accompanying waste, which arises from the applied technologies and procedures. According to that strategy, waste processing systems provide services to production plants which involve waste management. However, the waste processing industry in some cases also produces goods. When selecting the waste recovery or neutralisation method, the best available technologies, referred to in the BREF documents, should be taken into account. BREF documents concerning the following branches are important to inorganic chemical industry: production of large volume inorganic chemicals, fertilisers, specialist inorganic chemicals, chlor-alkali industry and waste processing.

The types of waste produced by industry are enumerated in the Regulation of the Minister of Environment on the catalogue of waste [13]. It classes waste into groups and each group is assigned a code – the code for inorganic chemical industry waste is 06. Waste classed as 06 group waste is produced by plants producing fertilisers, chemical plants, steelworks and copper smelting plants, plants which manufacture soda, pigments, medicines and cellulose. Research in waste management in inorganic chemical industry is conducted mainly at the Institute of Inorganic Chemistry in Gliwice (currently Inorganic Chemistry Section of the Artificial Fertilisers Institute) and at the Artificial Fertilisers Institute in Puławy and at chemical faculties of some universities: Wrocław University of Technology, West-Pomeranian University of Technology (formerly Szczecin University of Technology), Kraków University of Technology, the Nicolaus Copernicus University in Toruń and the Adam Mickiewicz University in Poznań. For example, the following research studies are conducted at the Institute of Inorganic Chemistry, which are associated with managing waste of inorganic chemical industry:

- research of phosphogypsum management,
- possibilities of utilisation of by-products of the soda technology;
- disposal of waste calcium fluoride from fodder phosphate production;
- disposal of used catalysts from chemical industry;
- research of neutralisation of waste of zinc hydrometallurgy;
- research of managing waste salts (e.g. iron sulphate, sodium sulphate, magnesium sulphate);

The following factors and limitations should be taken into account when developing scenarios for inorganic chemical industry waste management:

- new legislation on waste management and regulations connected with the IPPC Directive, making it obligatory to obtain an integrated permit;
- increased cost of using the environment;
- cases of restricting or shutting down chemical production if it is impossible to store the waste produced in it in a full-up waste dump;
- implementation of the REACH programme, one of its aspect being the manufacture of new products from industrial waste;
- restricting factors arising from implementation of the environmental standard ISO 14000, implementation of the Responsibility and Care programme and carrying out environmental analyses by the LCA method;

It is important for the project in question that the following issues should be taken into account:

1) Utilisation of waste and reduction of its amount, especially phosphogypsum, which is produced in the process of phosphoric acid manufacture, especially by using the products, obtained in the process of neutralisation, in road construction.
2) The technological process of soda production will still be based on the Solvay method, which has been improved but whose principle remains the same, with the use of the same raw materials and producing the same waste and by-products in the process. One of the aims should be broader use of soda lime in agriculture and in building construction as well in sulphur removal from CHP plants

Table 1

Major inorganic chemical industry plants in Poland where waste is produced

Plant	Total value of production output sold in 2007 million PLN	Major inorganic and fertiliser products	Major waste
Chemical plants affiliated with the CIECH Group			
IZCh Soda Mątwy S.A.	505	Calcined soda, baking soda, precipitated chalk, calcium chloride, hopcalite, sorbents	Waste from soda and salts production
JZS Janikosoda S.A. Janikowo	303	Calcined soda, precipitated chalk, evaporated salt, soda lime	Waste from soda and salts production
Gdańskie Zakłady Nawozów Fosforowych „Fosfory" sp. z o.o	313	Sulphuric acid, phosphorus and mixed fertilisers	Phosphogypsum
ZCh Alwernia S.A.	158	Phosphorus and chromium compounds, calcium and magnesium nitrates	Chromium waste
Vitrosilicon S.A.	150	Inorganic silicon compounds	Water glass filtration waste
Chemical plants not affiliated with the CIECH Group			
ZChem. Police S.A.*	1.822	Sulphuric acid, phosphoric acid, ammonia, ammonium phosphate, NPK complex fertilisers, titanium white, iron (II) sulphate, fluorosilicates	Phosphogypsum, iron(II) sulphate
ZA Puławy S.A.*	2.504	Ammonia, nitric acid, sulphuric acid, ammonium sulphate, ammonium nitrate, hydrogen peroxide	No data
Anwil S.A Włocławek	2.041	Chlorine, soda lye, ammonia, nitric acid, ammonium nitrate, nitro-chalk	solid waste from salt electrolysis
Synthos S.A. Oświęcim*	1.841	Chlorine, soda lye, hypochlorite	solid waste from salt electrolysis, waste lime
ZA Kędzierzyn S.A.	1.648	Ammonia, nitric acid, ammonium nitrate, nitro-chalk	No data
ZA w Tarnowie-Mościcach S.A.	1.241	Ammonia, nitric acid, ammonium nitrate, nitro-chalk, chlorine, soda lye, silicon compounds, iron catalysts	No data
ZCh. Zachem S.A. Bydgoszcz	904	Chlorine, soda lye	No data
PCC Rokita S.A., Brzeg Dolny	720	Chlorine, soda lye	solid waste from salt electrolysis
ZCh Siarkopol Tarnobrzeg sp z oo	159	Sulphuric acid, phosphorus and complex fertilisers, sulphur, aluminium sulphate, cryolite	Silicofluoric acid
ZCh Rudniki S.A.	70	Inorganic silicon compounds, silica fillers, soluble sodium and potassium silicates	Water glass filtration waste
Chemia Wizów sp. z o.o.	Production stopped	Sodium tripolyphosphate	Phosphogypsum
LUVENA S.A. (formerly ZCh Luboń)	No data	Mineral fertilisers, washing agents	Silica, silicofluoric acid

*Public companies. Source: The "*Rzeczpospolita*" newspaper, 31.10.2008, and a study by the Inorganic Chemistry Institute

emissions. Other important issues include the use of sludge from brine purification and calcium chloride solutions.

3) The technology of titanium white production requires extended use and of iron(II) sulphate waste.
4) New technologies are needed to recover valuable components from used catalysts applied in inorganic chemical industry.
5) New, innovative methods of unit operations of waste disposal should be applied more broadly; these should include granulation, briquetting and utilisation of membrane techniques and nanofiltration.
6) Reclaiming contaminated post-industrial areas around existing waste dumps; it is an especially urgent issue to reclaim the soil contaminated with heavy metals, mercury, arsenic.
7) New technologies of hazardous waste stabilisation with ultimate utilisation of the product thus obtained.

So far, the issues of waste management in the inorganic chemical industry in Poland have not been covered by foresight analyses. The effect of inorganic chemical industry on the rest of the economy is significant and so it is extremely important for the economic development of the country to carry out the foresight process and to generate development scenarios for waste management in the industry.

Usability analysis for foresight results in practical applications

Due to high diversity of its branches (from chemical raw materials through cosmetics and pharmacy products to super pure substances, for example used by electronic industry), the inorganic chemical industry determines the status and development of virtually every branch of industry, economy and everyday life. Products of chemical industry play the following roles:

- cooperative for all the industry branches, e.g. it provides construction materials, anticorrosion protection agents, tyres, rubber technical products, paints, varnishes, pure chemicals, inorganic intermediates for the machine-building, motor, electric, electronic, chemical, papermaking, glass, textile, food, household chemicals industries;
- supply to other areas of the economy, e.g. agriculture (fertilisers, pesticides), mining (water treatment agents), transport (fuels, fuel and oil additives, tyres, paints and varnishes), building construction (plastics, paints, impregnants) and many other;
- market role, by providing a wide range of products for immediate consumption, such as medicines, cosmetics, household chemicals, paints and varnishes, plastic and rubber products, products for photography and phonography, chemical reagents, etc;

At the same time, inorganic chemical industry and fertiliser industry have a considerable impact on the environment, which results in unfavourable public perception of the economically important industry. Among potential effects on the environment, one may mention atmospheric pollution, wastewater discharge and solid waste production. Although almost in its entirety classed as non-hazardous, waste produced by inorganic chemical industry plants is a serious problem for them. This includes storage-related cost: storage fees, construc-

Table 2

Detailed assignments and project milestones „Inorganic waste of chemical industry – technology foresight"

No.	Name of assignment	Abbreviated description of the assignment	Institutions responsible for carrying out the assignment
1	Organisation, publicity and portal of the Project	Creating the project portal: www.inorganicwaste.eu Recruitment of external experts and contacting them. Editing the website, surveys, information on the project, correspondence. Project publicity and PO IG	IICh
2	Determination of the study areas, current situation of chemical industry and state of knowledge on technology development	Determination of the state of knowledge and technology in the study subject matter. Updating the list of inorganic chemical industry waste. Forecast of the industry development.	IICh
3	Preliminary analysis – state of legislation – current and forecast for Poland and the EU; exploration of low-waste and waste-free technologies	Current state of legislation in Poland and in the EU as a controlling factor in the industry and waste management. An analysis of legal acts which are important for development of inorganic chemical industry by 2030.	Environment Protection Institute
Milestone 1: Report – determination of the state of knowledge, taking into account the legal factors			
4	Adaptation and implementation of foresight methodology	Based on the outcome of assignments 2 and 3 – adaptation of typical foresight methods to the Project	The Foundation
Milestone 2: Methodological report			
5	Carrying out the study, Delphi analyses, expert panels	Creating the knowledge base and expert base. Developing the study survey for the Delphi method (I and II round), Entering and analysis of data Discussions in the main panel and in thematic panels. Comprehensive analysis of the results.	IICh IEP
Milestone 3: An analysis of the results of the Delphi study and the expert panels			
6	Preparing development scenarios and final reports	Carrying out an optimisation analysis and generating several development scenarios at various boundary conditions based on the results of assignment 5 and by the methods developed in assignment 3. Preparing the final report in the full and abbreviated form.	The Foundation IICh IEP
7	Final conference. Conclusions for the plants and economic organisations concerned and the Ministries.	Organisation of the final conference Printing the materials. Disseminating the Project results in various forms.	IICh IEP
Milestone 4: Final report			

tion and maintenance of waste dumps, constant monitoring of eluates, gas and dust emissions, etc., as well as environment use charges. Waste-related problems may result in changes of the plant production profile and, in extreme situations, even in its liquidation. One of examples is the Gdańskie Zakłady Fosforowe, which hold authorisation for phosphogypsum storage until 2009. Another is Zakłady Chemiczne Tarnowskie Góry, which was liquidated in early 1990's due to a threat associated with waste storage (including hazardous waste). The problem of the waste has had to be dealt with by the authorities of the Province of Silesia.

Identification of potential receivers of foresight analysis results

Virtually all inorganic chemical waste is dumped at huge waste dumps and is used to a very small extent. According to the data of the National Waste Management Plan 2010, about 92 million Mg of 06 group waste was stored at waste dumps at the end of 2004 [6]. At the end of 2008, there was 100 thousand Mg of waste. The data indicate that group 06 waste accounts for the largest stream of waste produced in Poland. The greatest amounts of waste is produced by mining industry – 58.3% of the entire waste, in power industry – 23,0%, in food industry – 7.3% , in the systems and devices used in waste management in wastewater treatment plants and in plants producing potable and process water – 4.7% and in the inorganic chemical industry - 2%. The largest amounts of waste are produced in the south of Poland, in the provinces of: Silesia (ca. 41.9%), Lower Silesia (26.9%) and Małopolska (7.3%) [14].

Major inorganic chemical plants which produce inorganic chemical products (by the annual output value) are shown in Table 1. The plants are also the greatest waste producers. In terms of quantity, the biggest problem is posed by phosphogypsum, practically unmanaged in the whole. According to Inorganic Chemistry Institute data, the following amounts of phosphogypsum are stored at waste dumps:

- Z Ch Police S.A.- 83 millionMg,
- Gdańskie Zakłady Nawozów Fosforowych FOSFORY S.A. – 17 million Mg (annually 189-200 thousand Mg)
- Chemia Wizów sp. z o.o.-3.5 million Mg (currently the production has been stopped; it has not been resumed after the plant bankruptcy).

Significant problems are also posed by waste from soda industry and chromium waste. At the end of 2007, waste dumps contained the following amounts of waste: Zakłady Soda Mątwy 11.9 million Mg, Janikosoda – 1.4 million Mg. The waste dump at ZCh Alwernia S.A. currently contains over 3 million Mg of chromium waste (the amount is not increasing). In total, there is about 236 thousand Mg of waste lime from soda production/year [14].

Project schedule – description of the research assignments

The goal of the Operational Programme "Innovative Economy" is to strengthen the role of companies in creating the knowledge-based economy. The objectives of the programme include: strengthening the competitiveness, increasing the influence of science on the economy and strengthening international links of Polish science and economy [15].

The project entitled "Inorganic waste of chemical industry – technology foresight" is strongly associated with the industry through the research programme which closely responds to precisely defined

needs of businesses. Foresight is a modern planning tool, which indicates the most readily socially accepted actions that the state's financial assistance should be focused on. Foresight results in the form of development scenarios help the decision makers to make economically sound and socially accepted decisions, thereby implementing the principle of sustainable development. Increasing the role of science in economic development is expressed, for example, by carrying out development anticipating work, including forecasting work, based on the knowledge and experience of eminent representatives of scientific and industrial circles. The chemical industry seeks solutions for managing waste which is inherently linked with manufacturing of essential chemicals, or for gradual replacement of environmentally ineffective technologies and products with alternative ones which generate less waste, especially such that do not produce waste which is hazardous or difficult to manage. The problem concerning inorganic chemical waste may prove decisive for the industry development, even for manufacturing of all products currently supplied by the industry.

The scope of the foresight analysis will include: an analysis of waste management as well as new and existing trends in research which aim at developing environmentally friendly technologies, generating less and less difficult-to-manage waste. The analysis results for the state so far and those generated at various boundary conditions as well as the most probable development scenarios for the inorganic chemical industry waste management will be passed on to the decision makers in the government and economic administration and to everyone concerned. The project outcome should serve as the basis for anticipating actions in the economic area and should be used for development and subsequent implementation of scientific and innovation-related policy within the area covered by the study.

The project implementation will include discussion panels, thematic sessions at scientific conferences, analytic studies carried out by the Delphi method, an Internet portal, a knowledge base on waste and technologies and an expert database. The project schedule provides for application of modern quantitative and qualitative methods to support forecasting and foresight studies, which is a guarantee that the concerned authorities will receive objective expert reports and development scenarios. The planned assignments are presented in Table 2.

Summary

So far, the issues related to waste management in inorganic chemical industry in Poland have not been covered by foresight analyses. The effect of inorganic chemical industry on the rest of the economy is significant and therefore carrying out the foresight process and generating development scenarios for the economy is extremely important for the economic development of the country. The Project will include the following analyses: problem analysis, developing the study model and development scenarios for inorganic chemical industry with the use of modern methods of research and analysis, typical of the foresight process. The Project outcome will include strategic documents in the form of the final report containing development scenarios and conclusions for decision makers. Those concerned will be provided with analysis results in the form of the full report, brief report for the public and a report for economic decision makers. The study reports with the development scenarios will be provided free of charge to all those concerned. The project outcome will include three scenarios of the industry development, generated at various boundary conditions: neutral, pessimistic and optimistic. The project results will be implemented by scientific organisations which carry out the project itself as well as the economic and social organisations which have confirmed their interest in the Project results by submitting the relevant letters of intent. Conferences will be held to present progress and results. It is expected that the conferences will be attended by representatives of business and scientific circles, economy and regions managing authorities as well as environment protection and industry. In a longer perspective, implementation of the Project results, i.e. founding the development of the economy and chemical companies on the forecast scenarios, should contribute to reduction of the amount of waste produced per unit value of the inorganic chemical industry production output and to improvement of living conditions for the population.

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