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Transformation of Ecological Aspects of Industrial Symbiosis in Post-Industrial Society

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Abstract: Industrial symbiosis takes place in the social milieu and is addressed in light of opportunities for exploitation of ecologic, economic and social synergies. It is understood as a relationship between two or more social actors, involved in exchange of material resources, water or energy, where each actor follows its own benefits, while contributing to the benefits of other actors and society in general. This article studies the transformation of ecological aspects in post-industrial society based on secondary data. First, we focus on potential identification and classification of ecological aspects of industrial symbiosis. Later, we develop an approximation of the general concept of ecological aspects. We establish the way in which ecological aspects in post-industrial society – the society of information and knowledge – transformed as result of different ecologic and social influences. The article links transformation of ecological aspects to an increasing importance of education, environmental protection and science, and the presence of rapidly growing information technology.

Key Words: Industrial Symbiosis, Industrial Symbiosis Networks, Ecological Aspects, Transformation, Post-Industrial Society.

Introduction

Industrial symbiosis represents an interdisciplinary research environment, the primary research field of which belongs to ecology, economy as well as sociology, while related industrial symbiosis research is also being conducted in the field of biology, geography, chemical engineering, logistics, supply chain management and waste management. Some authors (Chertow 2007, Howard-Grenville et al. 2008, Gingrich 2012) define industrial symbiosis as an approach to industrial ecology[32]; as synonymous to industrial ecology (Phillips et al. 2005); as subset of industrial ecology (Chertow et al. 2005); activity within industrial ecosystem[33] (Rui et al. 2010); eco-industrial symbiosis representing circular economy on local and regional levels with sustainable effects and approaches to environment (Hartard 2008); or as one of the three levels of industrial ecology research (Hartard 2008). Industrial symbiosis exists in the social milieu and is studied through its opportunities for exploration as well as ecological, economical and social synergies. In fact, it can be categorized into an industrial ecosystem, which we see as environment, in which social actors manage transformation of material/water/energy resources into raw material, while industrial ecology and other fields of research examine this transformation, carried out through industrial symbiosis, on their own. In accordance with the four flows, typical of industrial symbiosis networks, we speak of ecological aspects of industrial symbiosis in terms of exchange of material resources between social actors. A large post-industrial society with its emphasis on information in light of

[32] Industrial ecology is a scientific discipline, interested in material and energy flows in industrial and service activities with the purpose of appropriate use and reuse of these resources (White 1994).

[33] Industrial ecosystem is an integrated system, which provides for an optimized use of energy, material resources and sewage, which are used as raw material for other manufacturing or non-manufacturing processes (Frosch et al. 1989).

new knowledge represented a significant shift in ecological aspects of industrial symbiosis.

Theoretical Framework

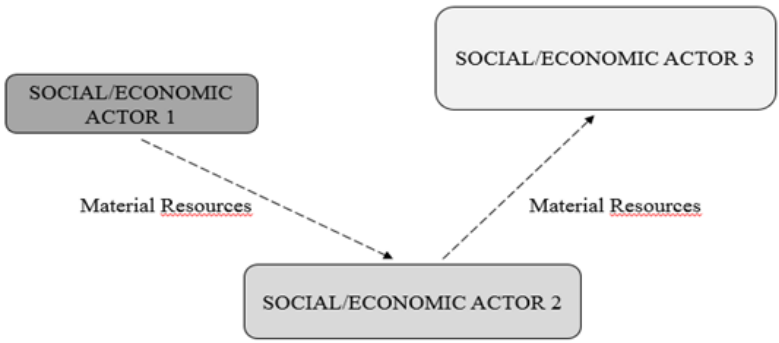
Industrial Symbiosis

In its natural environment, symbiosis is linked to the concept of mutualism, where at least two different parties exchange a material resource, energy or information for their mutual benefit (Huber 2012). Chertow (2000) defines industrial symbiosis as a collective approach, which includes physical exchange of materials, energy, water, and byproducts between social actors in different industries with the intention of gaining a competitive advantage. On the other hand, Manahan (1999) defines industrial symbiosis as mutually-dependent relationship between two social actors, which exchange material resources and energy for their mutual benefits, where the intention of each partner is to increase their own benefits as well as the benefits of the other partner. As a paradigm, it can be seen as a relationship between two or more social actors, involved in exchange of material resources, water or energy, where the intention of each partner is to increase their own benefits as well as the benefits of the other partner and society in general. Social or economic actors in the exchange of material resources, water or energy are represented by industrial as well as non-industrial companies. Beside companies, social actors are also local communities, local authorities, educational institutions, research centers, ministries, and government and similar agencies on a national and international level.

Chertow (2000) has defined a minimum criterion of industrial symbiosis, which demands the involvement of at least 3 social actors in the exchange of at least 2 material resources. Following is an example of industrial symbiosis in the sense of physical exchange. A social actor – if a company, then economic actor – named Company 1, sells its waste, produced as result of their primary business activity, to another economic

actor, named Company 2. After processing, Company 2 uses the waste as raw input material for production of another new product, which represents primary activity of Company 2. Company 2 sells by-products resulting from its primary activity to a different economic actor, named Company 3. Company 3 processes the waste and uses it as raw input material for production of a new product. Figure 1 displays a graphic representation of the minimum criterion for the existence of industrial symbiosis.

Fig. 1: Minimum criterion for the existence of industrial symbiosis (Chertow 2007)



There are four flows connecting the actors: information, material, financial and knowledge flow. Information flow runs in both directions, i.e. connects all actors involved. Material flow begins with the partner selling the material resources – in this case from social actor 1 towards social actor 2 and next towards social actor 3. Financial flow usually runs in the opposite direction – in this case from social actor 2 towards social actor 1 and from social actor 3 towards social actor 2. In practice, financial flow can be excluded when only material exchange occurs between the partners.

Knowledge flow is a very important aspect, enabling social actors to exchange know-how and experience. Knowledge flow is multi-directional, same as information flow. The advantages of industrial symbiosis for social actors and society alike apply to ecological, economical, and social areas. In ecological sense it is carried out through joint reuse of used material resources; in economical sense it applies to joint savings from purchasing new material resources and correct disposal of used material resources; in social sense it is visible through joint social concern in terms of established approaches in environmental management and informal networking between social actors, bringing new knowledge and best practice into all other fields of management.

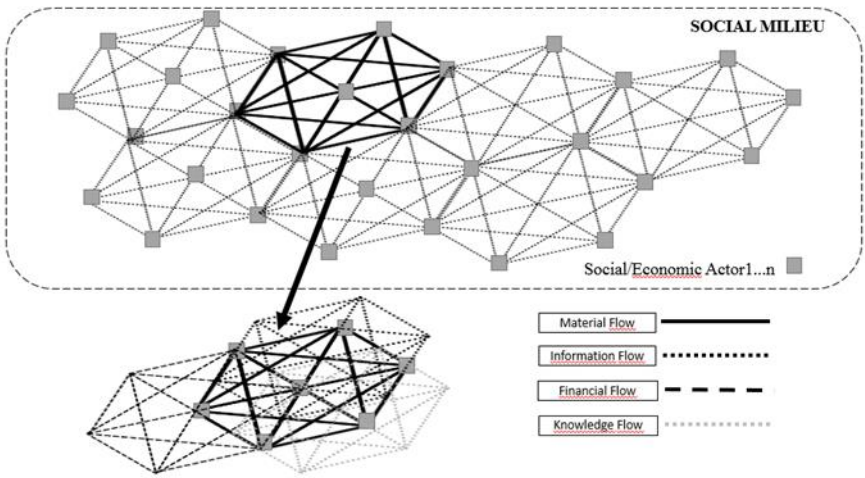
Industrial Symbiosis Networks

Industrial symbiosis can be studied through industrial symbiosis networks, as it represents their integral part. Domenech (2011) provides two definitions of industrial symbiosis, based on different approaches to the research of industrial symbiosis in industrial symbiosis networks. One approach is eco-industrial park, the other is eco-industrial network. Eco-industrial parks are spatially-defined entities, while eco-industrial networks are information centers (Domenech 2011). Hartard (2008) also mentions so-called cooperation of neighbors, representing cooperation between neighboring companies and industrial parks on a local level (Hartard 2008). On the other hand, he defines eco-industrial parks and eco-industrial networks as cooperation between companies within a region (Hartard 2008). Chertow (2000) also names geographical proximity of partners as one of the conditions for industrial symbiosis. Industrial symbiosis networks can be seen as virtual networks, which are present and active on regional, national or international level, where industrial symbiosis can be carried out in accordance with the geographical proximity criterion. Another definition of industrial symbiosis networks compares these networks with eco-industrial parks and industrial ecology (Mirata 2011); while a different definition states that industrial symbiosis and eco-

industrial parks represent key concepts of industrial ecology (Lehtoranta et al. 2011).

Uzzi (1997 in Domenech et al. 2010) focuses on 3 typical characteristics of industrial symbiosis networks: trust between social actors; transfer of information (which also includes transfer of knowledge); and joint resolution of problems. This means that social actors, which act as nodes to connect different elements of industrial symbiosis networks, are more efficient in adapting to social environment with its constant, daily changes depending on current trends in supply and demand. Industrial symbiosis networks connect social actors, which cooperate in carrying out industrial symbiosis in order to fulfill their own economic, ecologic and social goals. Like other networks, they consist of nodes and connections. Social or economic actors will represent the nodes of industrial symbiosis networks and cooperation between these actors will represent the connections between the nodes. The connections are represented by four flows: information, material, financial, and knowledge flow. Material flows are carried out on local and regional levels; whereas industrial symbiosis networks exist on a national or international level. Flows between the nodes can move by different scenarios. In scenario 1 all four flows can move between the nodes; in scenario 2 three flows can move between the nodes; in scenario 3 and 4 only one flow – usually the information flow, which acts as precondition for at least one more flow (material, financial, knowledge) between the nodes. Social actors in industrial symbiosis may only exchange advice and experience, not necessarily material resources. In this case, one of the existing combinations of scenario 2 is possible. Figure 2 shows a scheme of industrial symbiosis networks in the social milieu.

Fig. 2: Industrial symbiosis network as part of social milieu



Extant case studies of industrial symbiosis and of industrial symbiosis networks

The existence of industrial symbiosis world-wide is confirmed by 20 large and internationally acclaimed case studies, which are mentioned in the works by different researchers in the field of industrial symbiosis and industrial symbiosis networks (Onita 2006). Case studies on the practical implementation of industrial symbiosis were performed on four continents, namely Europe, Asia, America and Australia (Onita 2006). All 20 cases of industrial symbiosis represent a form of exchange in material and energy resources between economic partners/companies. Table 1 shows 20 case studies on industrial symbiosis.

Tab. 1: Case studies of industrial symbiosis and industrial symbiosis networks (Onita 2006)

Case study	Country
Alberta	Canada
Golden Horseshoe	
Burnside Industrial Park	
Nova Scotia	
Montreal	
Sarnia-Lambton	
Tilbury Industrial Park	
Brownsville Eco-Industrial Park	USA
North Texas	
Gladstone Industrial Area Network (GAIN)	Australia
Kwinana Industrial Area (KIA)	
Guayama	Puerto Rico
Kalundborg	Denmark
Kawasaki Zero Emission Industrial Park	Japan
Map Ta Phut	Thailand
National Industrial Symbiosis Programme (NISP)	UK
Ora Ecopark	Norway
Rotterdam	The Netherlands
Styria	Austria
Tampico	Mexico
Alsen Cement and Salzgitter Steel Works	Germany

Since 2003 National Industrial Symbiosis Programme (NISP) is in place in the UK, which aims to use industrial symbiosis as a solution for re-processing industrial waste into raw material. Unlike research in the field of ecology and economy, industrial symbiosis research is still in its development phase. University College in London deals with industrial symbiosis, industrial symbiosis networks and social network theory from a social perspective. The research resulted in a 2010 doctorate dissertation titled "Social Aspects of Industrial Symbiosis Networks". The dissertation was written as a reaction to the current (developing) status of social research in this area (Domenech 2010). Its conceptual framework includes the key flows, social and discursive dimensions of industrial symbiosis

networks; whereas the research focuses on dynamic analysis of interactions between social actors (Domenech 2010).

Ecological Aspects of Industrial Symbiosis

Ecological aspects of industrial symbiosis in general can be interpreted as reasons for implementation of industrial symbiosis, as advantages of industrial symbiosis, as indicators of industrial symbiosis, but also as characteristics of industrial symbiosis. Given the four flows, which can be identified during implementation of industrial symbiosis in industrial symbiosis networks, we can speak of ecological aspects of industrial symbiosis when material flow is present or when material resources are being exchanged between social actors. Ecological aspects are general or specific. General ecological aspects include processing of previously used material resources, which come out of the industrial/non-industrial process as waste, re-use of processed material resources as raw material for industrial/non-industrial processes, processing of by-products and other material resources, which are not categorized as waste, in other industrial/non-industrial processes. Because we can name the afore-mentioned ecological aspects general, this implies that they can be present in all industrial and non-industrial processes, where industrial symbiosis is performed (exchange of material flow between social actors). This complies with ecologic advantages of industrial symbiosis, such as decreasing the use of new material resources, decrease in emissions, exchange of waste and other material resources, and decrease in use of renewable energy sources (Mirata 2011). Specific ecological aspects of industrial symbiosis can be defined as those aspects of ecology, which apply only to individual industrial symbiosis networks within specific industries. For example, if we take a look at industrial symbiosis networks in the steel industry, then material flow is represented by an exchange of specific steel material resources (which can be steel waste and/or

byproducts). Beside steel-type material resources, other materials can be exchanged between the actors.

If researchers interpret ecological aspects of industrial symbiosis as indicators of industrial symbiosis, we can use these aspects to recognize and study:

- new approaches and practice for minimizing any environmental effects,
- development/level of development of industrial symbiosis,
- socio-cultural aspects of industrial symbiosis,
- economic aspects of industrial symbiosis,
- efficiency of industrial symbiosis in individual social actors – status before and after its implementation,
- during the performance of industrial opportunities, opportunities and challenges, which are unrelated to industrial symbiosis, are identified or become visible.

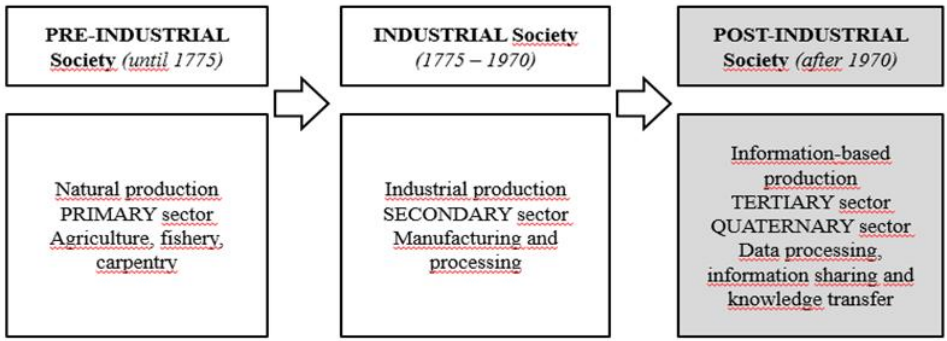
In the framework of ecological aspects of industrial symbiosis we can study individual ecological aspects, which are present during implementation of industrial symbiosis within a random industrial symbiosis network, thus depending on the purpose and goals of research. We can also study all ecological aspects, which are present during implementation of industrial symbiosis. Although we only focus on ecological aspects of industrial symbiosis in this article, we should also emphasize that ecologic aspects are inextricably linked to economic and socio-cultural aspects. This means that one of the three reasons – ecologic, economic or socio-cultural – is required for performance of industrial symbiosis. When one of the reasons for performing industrial symbiosis is present, we speak of advantages on ecologic, economic and socio-cultural area and related three aspects of industrial symbiosis. All three reasons or only two reasons can be present (with potential combinations between them) – in any case the ecologic, economic and socio-cultural advantages will be visible and all three aspects can be studied. In general, ecological

aspects of industrial symbiosis can be defined as reasons for the performance of industrial symbiosis, which show up as indicators of industrial symbiosis, as well as its advantages and characteristics.

Post-Industrial Society

For post-industrial society we normally use terms, such as society of services, information society, society of knowledge and 21st century society. Daniel Bell was one of the beginners and advocates of post-industrial society, who defined industrial society in terms of the quantity of goods and post-industrial society in terms of quality of life, measured by its services, comfort, health, education, recreation and art – all this is desired and available to everyone (Bell 1979 in Hansen 2001). Through chronology, the concept of "post-industrial" closely follows that of "industrial", which follows the concept of "pre-industrial". Bell (1976 in Hansen 2001) defines pre-industrial sector as one based on economy, which involved agriculture, mining, fishing, wood-processing and other natural activities. Industrial sector was based on using machines and energy; whereas post-industrial sector is based on information processing for the purpose of information and knowledge exchange (Bell 1976 in Hansen 2001). According to classification of sectors into primary, secondary, tertiary and quaternary we see post-industrial society as transition into society of services (Cohen 2011). With the occurrence or beginning of society of services, the person itself becomes raw material for processing (Cohen 2011). Thus, in post-industrial society most people are involved in production of services and information instead of manufacture of tangible goods. Figure 3 displays the transition from pre-industrial into industrial and from industrial into post-industrial society.

Fig. 3: Characteristics of transitions from pre-industrial to post-industrial society



English-speaking economists have coined a term in accordance with Fourtié's idea of "face-to-face" work, which demands a direct contact between the manufacturer and his client (Cohen 2011). Link (2009) describes post-industrial society as radical transformation of economical and political structures, which incited dramatic shifts in societies with a high level of knowledge and highly-educated work force available to advise the government and companies. The key element for post-industrial society is information and service production as well as theoretical knowledge in the tertiary and quaternary sectors; and person, who is appropriately trained and capable of performing complex tasks, demanded by post-industrial society. A job in post-industrial society includes working with knowledge. Bell (1973) calls post-industrial society “society of knowledge”, because the sources of innovation are based on research and development. Knowledge is important in all fields – technology, economy and society. Bell (1973) defines post-industrial society in two ways:

1. Sources of innovation are based on research and development, creating a new relationship between science and technology – theoretical knowledge becomes central;
2. The field of knowledge becomes very important, if we judge according to gross domestic product and the share of people working in this field.

The quality of (processing) information and knowledge, which were critical for post-industrial society and resulted in research and development were also critical for the innovations in scientific and technological fields. This began to change the opinions of experts and the educated and information became more important than the physical strength of a person working at a factory. Post-industrial society also expedited the development of industrial symbiosis in its updated conventional form. From the beginning of post-industrial society, industrial symbiosis was performed through material and financial flow, information flow was performed in oral and written form only, and knowledge flow was pushed into the background; whereas all this is changed later on in post-industrial society. Information flow, supported by information and communication technology, becomes critical for the existence of material and physical flow as well as knowledge flow in industrial symbiosis. Post-industrial society has also impacted the relationship towards natural environment.

Development of Industrial Symbiosis and Transformation of Ecological Aspects of Industrial Symbiosis in Post-Industrial Society

First instances of industrial symbiosis in history can be found in the period of commodity exchange (goods-for-goods), when people exchanged goods (not waste, because material resources for survival were rare at the time). When a person no longer required a material commodity and instead required a different commodity, offered up his commodity for exchange. After the commodity exchange period came industrial symbiosis in the

form of commodity-for-money exchange. In this case, a person sold a commodity he no longer required (could be waste or not) to another person in exchange for money. It is hard to say that the afore-mentioned examples of industrial symbiosis contained any sort of ecologic or social reasons. The primary reason for exchange was survival, later on followed by the need for money, thus we can speak of economic reasons. It is also hard to speak of an optimum use of material resources, which is another characteristic of industrial symbiosis, although such activity was already present in some areas. The advent of industrial society increased the optimum use of (rare) material resources in manufacturing processes and begins to develop industrial symbiosis (although named differently) for its economic benefits.

In 1937 industrial symbiosis is first mentioned and described in the article "Geography of Glass Manufacture at Toledo, Ohio" by Walter G. Lezius (Lezius 1937). In 1947 both industrial symbiosis and industrial ecology are mentioned in the article "The General Principle of Industrial Location" as a "Law of Industrial Ecology" by George T. Renner (Renner 1947). The latter defines industrial symbiosis as merger of two or more different industries, where each industry tries to find an optimum access to material components and material elements (Renner 1947). In 1967 the president of American society for scientific progress writes about cases of industrial symbiosis, in which one industry neutralizes or uses waste from another industry (Spilhaus 1967). 1989 was another inspirational and landmark year for industrial symbiosis, when first research was designed and performed (Chertow 2007) in Kalundborg, Denmark, where companies/economic actors in connection to their local administration developed a complex network for exchange of waste material to be re-used as raw material in industrial processes. The project involved 11 companies and the research included a total of 13 projects (Van Berkel et al. 2008). This and other research, which followed, began to show, mention and achieve its ecologic, economic and social aspects.

Cases of industrial symbiosis before 1937 can be named informal types of industrial symbiosis and can be further divided into preliminary and final form. Preliminary forms include exchange of material goods, while final form includes exchange of goods and financial resources. First examples of a formal type of industrial symbiosis appeared after 1937, when industrial symbiosis was first named as such and included all three aspects. In relation to transformation of ecological aspects of industrial symbiosis in post-industrial society we speak of a passage or transformation of ecological aspects from industrial society into post-industrial one. Before post-industrial society, only re-processing of waste was seen as ecological aspect of industrial symbiosis, although it wasn't performed for its beneficial environmental effects, but rather for economic reasons. The first mention of environmental aspects and beginnings of ecology can be traced back to the time of Aristotel, but the ecological aspects of industrial symbiosis, as we know today, only began in the post-industrial society. We can say that formation and transformation[3] of ecological aspects of industrial symbiosis in post-industrial society were impacted by the same factors as development of industrial symbiosis and types of industrial symbiosis. Information was a critical element of this transformation of ecological aspects of industrial symbiosis in post-industrial society: quality of information became more important than quantity thereof; information exchange is supported by information technology; information and knowledge is processed to be used in tertiary and quaternary sectors. At the same time, the increase in the level of knowledge and education inspired a new opinion on natural environment. In the 1960s ecology emerged as a new science, fueled by concerns for the current and future condition of our environment, bringing with it industrial ecology as a new scientific discipline. Industrial ecology was primarily interested in the large environmental impacts of the industry. In post-industrial society, industrial ecology was the one of the first scientific disciplines to begin identifying and researching ecological aspects of industrial symbiosis based on relevant cases of industrial symbiosis, scientific development and ecologic innovations. In this period, industrial ecology connected to and cooperated with other sciences, which support

the research on industrial symbiosis – mostly economy, sociology and biology. The transformation of ecological aspects of industrial symbiosis was greatly eased by the development of information society with the rise of computers, hardware and software, thus information society as the synonym for post-industrial society.

Ecological aspects of industrial symbiosis have and will continue to transform under the influence of factors, brought on by new knowledge, new experience and information technology, new demands in environmental protection, and related concern for society in general. Up to the 21st century, ecological aspects in post-industrial society have transformed so much to become indicators of industrial symbiosis as best practice in areas of ecology, economy and social development.

Future Research

Our next stop involves a detailed research of industrial symbiosis in light of its importance in industrial symbiosis networks in individual social milieus. With this research we wish to identify and define the conceptual framework of industrial symbiosis networks, which are operating on a regional, national and international level. The research will require a pilot study, which will be our basis for all further research on industrial symbiosis as it will provide an overview of the status of industrial symbiosis in Slovenia, where it is currently in its development stage. Industrial symbiosis and its (informal) forms in Slovenia can be categorized into three groups, which are present on micro level of the social milieu and could be useful for our research. The three groups were designed based on secondary resources on industrial symbiosis, which are available on the websites of companies from all statistical regions of the country. The first group contains companies, which are actively involved in industrial symbiosis and use similar terms to name it, such as eco symbiosis, industrial eco symbiosis, etc. The second group contains companies, which

are involved in so-called final (informal) forms of industrial symbiosis, but use a different term for this type of operation. The third group contains companies, which are thinking about joining an industrial symbiosis venture, understand it as an essential social practice and plan to incorporate it in their future operations. We wish to study the current status of industrial symbiosis in Slovenia within industrial symbiosis networks, which we could form based on information about connections and cooperation between social actors. The primary goals of our research are:

1. identify a general concept of industrial symbiosis in Slovenia,

2. design a conceptual framework of industrial symbiosis networks,

3. identify ecological aspects of industrial symbiosis,

4. determine the impact of ecological aspects on social actors in industrial symbiosis networks.

Primary data will be collected using semi-structured interviews on the micro level, where we will first define relevant social actors, which could provide us with representational and high-quality information. When selecting companies, we will focus on ecologically- and sustainably-oriented companies. Among these companies we will select micro, small, medium and large companies from a list of processing companies, managed by Slovenian Environment Agency – at least five companies from every statistical region. Semi-structured interviews, used for collecting data, will include four sets of questions. An analysis of the interviews we give us an insight into existence and connections between social actors in industrial symbiosis networks, which we had foreseen. Data will be processed in a program for qualitative data processing, which we will select during our research.

The results of this pilot study will provide answers to our current questions on industrial symbiosis in industrial symbiosis networks. It should provide an insight into the current status of industrial symbiosis in our country. As previously mentioned, it will support our detailed research on industrial symbiosis within industrial symbiosis networks in a specific social milieu. Primary goals of the research are:

1. identify socio-cultural aspects of industrial symbiosis networks,

2. determine the impact of socio-cultural aspects on the structure of industrial symbiosis networks, and

3. determine the impact of socio-cultural aspects on social actors in industrial symbiosis networks.

We will try to find answers to questions above through research program, which we are currently developing. Beside the hard and soft sciences, the program will also include important practical applications, such as developing the tools for incorporating industrial symbiosis into natural, technical and socio-cultural environment. The suggested research program would include dynamic complex networks, which form technical, natural, computer and social systems outside their borders. The goal of this program is to develop a theoretical model, approaches and analytical methods, which would enable acquisition of knowledge about the foundations of industrial symbiosis and its characteristics, which should be monitored.

Conclusion

In this article we presented industrial symbiosis as a current and necessary practice, which brings about ecologic, economic and social advantages to the social milieu for social actors as well as society in general. We have presented a general concept of industrial symbiosis and

its placement in industrial symbiosis networks. We also defined ecological aspects of industrial symbiosis and characteristics of post-industrial society, which caused a transformation of ecological aspects of industrial symbiosis. These aspects will continue to evolve under the influence of factors, supported by new knowledge, new information technology, new demands in environmental protection, and the concerns about society in general. Since ecological aspects of industrial symbiosis in post-industrial society in the 21st century have already transformed to such an extent that they indicate best practice in industrial symbiosis in light of ecology, economy and social matters, it would be wise to continue research in this direction, i.e. how social actors recognize and identify individual aspects and what individual aspects represent for social actors in industrial symbiosis networks. First, we will design a pilot study in order to review the condition of industrial symbiosis in Slovenia, where it is currently in its development stage, and provide a foundation for future detailed research on industrial symbiosis.

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