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## Review Article

# Industrial Symbiosis: A Review on Uncovering Approaches, Opportunities, Barriers and Policies

### Abstract

The industrial symbiosis (IS) has been becoming increasingly popular from last decade of last century because of its prospect towards safeguarding environment and reducing usage of virgin materials through recycling. After emergence of symbiotic network, industrial clusters followed different approaches and faced different difficulties at their uncovering stages. Some successful symbiotic network showed great promise in reducing usage of raw materials. Policy regarding IS has a tremendous impact on the genesis, emergence, and development of it. In this study authors tried to review already followed approaches, benefit obtained and problem faced by the industrial owner along with generalized policy framework they needed at the very early stages of IS network. However, two approaches are followed by industries –planned approach and spontaneous approach though there are factors that helped to initiate symbiotic network. Obtained benefits from IS network can be classified into three categories and these are-environmental benefit, social benefit and economic benefit. On the contrary industrial networks also faced some barriers i.e. technological barrier, economic barrier, informational barrier, organizational barrier, regulatory barrier, uncertainty and risk of initiating IS network. Thus policies were formulated to ensure sustainability of projects and to overcome barrier. Policy initiatives helps to bring the cooperatives under same industrial symbiotic network, shape a symbiotic network and patronize the symbiotic networks by providing incentives. Industrial networks only sustains when all favorable conditions are easily available to those otherwise many prospective networks will fail to see the light of success.

## Introduction

With the emergence of human civilization, human started to extract and use resources from nature for subsistence and economic development. Unlimited resources gave us the opportunity to generate unlimited waste. Resource was not a matter of concern at that time as population compared to resource was insignificant. Unlimited extraction proportionately decreases the availability of resources thus generated unlimited waste, later on which became a great concern for us. Different strategies were taken to back the waste into production system. This thinking gave birth to an idea where different farms and entities collaborate together to enhance sustainable utilization of resource system commonly termed as industrial ecology.

The history of industrial symbiosis [1], is more than 150 years old. With the passage of time different economists, geographers and sociologists gave their views related to this topic. Previously common thought was that industries go oppose to the environment. Their opinions and case studies helped to establish a linkage between industries and environment to attain sustainability as the resources are limited. Granovetter [2], identified that cluster of firms in a territory achieved more success than others if they can develop untraded interdependencies such as flows of knowledge, customs or understandings and trust. Desrochers & Leppälä [3], discussed successive historical progression of industrial symbiosis. In his article, he compared past day's and present day's synergies. On the other hand, Chertow [4] showed how industrial symbiosis got international acceptance over time.

According to Frosch & Gallopoulos [5], industrial ecosystem is a system where consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process serve as the raw material for another process. It also functions as an analogue of biological ecosystems [5]. In the same year (1989), some inter related firms started to share their resources in Kalundborg, Denmark which set a mile stone in the field of industrial ecology and justified the theory of Frosch & Gallopoulos [5]. This new idea got recognition as "The industrial symbiosis at Kalundborg". 1989 is considered as an inspirational year for industry and environment by Chertow [6]. In that year a fundamental article was also published by Scientific American named "Strategies for manufacturing" by Frosch and Gallopoulos. The core of the article gave illustration of approaches, policies and ideal condition of sustainable industrial ecosystem. In that article Frosch and Gallopoulos deciphered that an ideal industrial ecosystem may never be attained in practice, but both manufacturers and consumers must change their habits to approach it more closely if the industrialized world is to maintain its standard of living and the developing nations are to raise theirs to a similar level without adversely affecting the environment. They also denoted that the consumption of energy and materials is optimized and effluent of one process ....serve as the raw material for another process [5]. Industrial ecology creates a sense what we should do and industrial symbiosis shows us a prospect what we can do in future. Symbiosis came from a Greek word "syn" means together and "biosis" means living, thus symbiosis means short term or long term relationship between two individuals. Industrial symbiosis is a concept used to describe geographically proximate inter-firm

relationships involving the exchange of residual materials, water and energy. Most accepted definition of IS was given by Chertow [4], industrial symbiosis, as part of the emerging field of industrial ecology, demands resolute attention to the flow of materials and energy through local and regional economies. Industrial symbiosis engages traditionally separate industries in a collective approach to gain competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity. But Lombardi & Laybourn [7] provided redefined definition which included emerging components of IS projects. According to them - IS engages diverse organizations in a network to foster eco-innovation and long-term cultural change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.

However, after emergence of Kalundborg, several industrial synergies have been discovered and initiated in 27 countries. More than 300 European and non-European eco-industrial parks [8] have already showed greater prospects. These industrial clusters will very likely to form a symbiotic network if they are provided with three primary privileges: (1) by product reuse, (2) utility or infrastructure sharing, and (3) joint provision of services [6]. Twenty five years have been passed and researchers identified key problems and provided their time dependent and area specific resolutions [9-11]. Another important component is policy instruments which have an opposite two fold effect, sometimes it helps in symbiosis formation or imposes restriction on industrial owners and sometimes policy fragmentation hinders potential projects and made it unsuccessful. So, approaches,

opportunities, and barriers and policy instruments can be taken as three important attributes of industrial symbiosis. Many review articles and full length research papers have already been published but there is still data deficit about the aforementioned components and more importantly none tried to review these three component altogether at uncovering stage. In this paper the authors put their concentration on the different approaches that enhance industrial symbiotic relations, opportunities, barriers and policies instruments irrespective of any symbiosis project.

So, the focus of the review is threefold, namely:

- To identify approaches taken to initiate to maintain industrial symbiotic projects.
- To review opportunities those have been identified by different researchers.
- To identify key policy instruments those enhance symbiotic relation between firms and industries.

### Approches and enabling factors

During 1800s, when industrialization had just started, the relation between natural resources and production system was linear. As the resources were limited to exploit, a non-linear relationship evolved in production system (waste as raw material). Industrial symbiosis gives material and energy efficiency along with better environmental sustainability.

Literature review gives us two distinct processes for arising industrial symbiosis initiatives- (i) self-organization process and (ii) third party planning or engineered process [6]. Organizational theory draws a distinction a between 'serendipitous' and 'goal-

**Table 1:** Difference between interventions in planned and spontaneous approach.

Agents	Planned approach	Spontaneous approach
Government	<ul style="list-style-type: none"> <li>• planning ordinance for eco- industrial developments, involving the design, development and management of the site</li> <li>• economic incentives: tax cuts for adhering companies, funding brown field/green field development, funding design teams</li> </ul>	<ul style="list-style-type: none"> <li>• environmental regulation: water, air and waste (target/ limits requirements:- management process</li> </ul>
Govt. institutions	<ul style="list-style-type: none"> <li>• economic incentive: financing and/or subsidies</li> <li>• part of design teams/management</li> <li>• material flow analysis/by-product or waste matching</li> <li>• informational and decision tools developers</li> <li>• intermediary to establish synergy</li> </ul>	<ul style="list-style-type: none"> <li>• emission of permits</li> </ul>
Private associations (e.g. industry, business)	<ul style="list-style-type: none"> <li>• intermediary to find "fitting" companies</li> </ul>	<ul style="list-style-type: none"> <li>• network development and promotion</li> <li>• information exchange platform</li> <li>• mediation role</li> <li>• monitoring</li> </ul>
Universities	<ul style="list-style-type: none"> <li>• part of design teams</li> <li>• material flow analysis/ by-product or waste</li> <li>• matching informational and decision tool developer</li> </ul>	<ul style="list-style-type: none"> <li>• uncovering of linkages</li> <li>• economic / environmental analysis of linkages</li> <li>• report of synergies</li> </ul>
Business	<ul style="list-style-type: none"> <li>• anchors at the development site</li> <li>• relocation at an industrial park</li> <li>• high rated flows of waste type materials and /or residual utilities; complementarities in material flows-</li> <li>• engines for jobs and attracting more businesses</li> </ul>	<ul style="list-style-type: none"> <li>• identification of business opportunities in resource management</li> <li>• economic validation of linkages</li> <li>• funding of uncovering/ discover opportunities-</li> <li>• network promotion regional networks / clusters</li> <li>• R&amp;D for reuse/ recycling technologies</li> <li>• green twiners</li> </ul>

Source: Costa & Ferrão [13].

directed' network processes. Serendipitous processes occur through the "happenstance of people meeting and liking one another," while goal-directed processes occur when "parties interact to achieve, plan, coordinate, or decide on their individual and collective activities. They showed how two different processes influence initialization and combined influence on IS resilience [12]. But Costa & Ferrão [13], deciphered a clear distinction between planned approach and spontaneous approach. They documented how different agents behave differently if they (agents) approached towards planned or spontaneous way. Interventions in planned and spontaneous approaches adapted from Costa & Ferrão [13], are given in Table 1.

From the planned and spontaneous approaches of industrial symbiosis, it is clear that the different entities (e.g. government, government institutions, business etc.) have some key roles to accomplish for achieving certain goals (i.e. reducing cost and getting higher benefits considering the environmental improvement). Government together with its institutions can play lead role by adopting some programs like reducing taxes or providing economic incentives for companies who adopt symbiosis in their production systems. Research organizations can help the organizations that adopt IS concept by providing the design, information on resources to take better decision. After setting up IS in industry/organization, they should develop their own capacity. In our view, the parties adopting IS may establish a certain department which will be responsible for updating inventories of water use, energy use, waste generation etc. This may increase initial production cost, but in the long run it will enhance the performance as the parties don't need seeking for help from other external organizations. As we know that industrial symbiosis is the synergies of collocated of industries; regional resource synergies improve flow and exchange of natural resources to achieve more productive use of material, energy or water. Bossilkov et al. [10], distinguished three types of regional synergies- *resource exchange*: what resource is being exchanged between companies; *processing involved*: the degree to which the "wasted" resource is being processed before it can be utilized by the other company (ies) involved in the synergy project; *synergies*: the business relation governing the synergy project (Table 2).

Efficient use of resources are the central concept in symbiotic network of industries. Water, energy are the two key and most important resources and almost every single industry is dependent

on it. Reuse of water is a better option as it would also decrease cost of energy use along with saving water for further use. Used water can be used largely for cooling purposes inside industries. Bilateral resource sharing can be of great importance as it would increase performance of the industries where both of the industries are in win-win situation and environmental aspects in also ensured. Before disposal of waste, useable items should be segregated from the non-useable. Again the non-usable items for one production system may be required by others. This process will diminish the larger volume of waste to a smaller one and industries will be benefitted economically also.

Similar type of synergies were critically studied by Chertow [4], she studied 18 eco - industrial parks and categorized them into five groups according to their material exchange and driving factors that enhance their formation and continuation. These discussed categories were mention as IS types by author herself. The types are as following-*Type 1*: through waste exchanges; *Type 2*: within a facility, firm, or organization; *Type 3*: among firms collocated in a defined eco-industrial park; *Type 4*: among local firms that are not collocated and *Type 5*: among firms organized "virtually" across a broader region. These are some ways how the industries can make a cluster. There are some factors that also help in formation of industrial cluster. According to Teh et al. [14], the determinant factors of industrial symbiosis are- (i) institution, (ii) law and regulation, (iii) finance, (iv) awareness and capacity building, (v) technology, (vi) research and development, (vii) information, (viii) collaboration, (ix) market, (x) geography proximity, (xi) environment issues and, (xii) industry structure. Apart from determinants, Boons et al. [15], mentioned 5 factors for industrial symbiosis. The factors were- (1) the need for a learning process and strategic vision, (2) issues related to the diversity of involved actors and its consequences for connectance and interdependency, (3) the requirement of trust and ways to foster it, (4) the presence of anchor tenants or coordinating bodies and the roles they can play in providing information, education and as a platform for communication, and ( 5) the presence of an enabling context, which may defined in terms of policies, regulations and other institutions but also in much broader terms such as cultural, structural, spatial and temporal embededness. In their article, they also deciphered role of institutional capacity for establishing IS and also distinguished 3 dimensions of institutional capacity as relational capacity, knowledge capacity and mobilization capacity. Van

**Table 2: Different types of regional synergies among industries.**

Type of resource exchange	Type of processing	Type of synergy:
<p><b>Water:</b> exchange and reuse of cooling water and process water, any collective treatment and recycling of wastewater.</p> <p><b>Energy:</b> shared use of energy infrastructure, co-generation and/or recovery of waste heat from steam and electricity generation.</p> <p><b>Non-process waste:</b> may include waste generated while carrying out routine or emergency maintenance, packaging materials, machinery components, general household waste, landscape waste, construction or demolition debris.</p> <p><b>Other:</b> this type of exchange generally features some sort of service or utility sharing</p>	<p><b>Direct use or reuse:</b> without any further processing except for transport and storage.</p> <p><b>Energy recovery or alternative fuels:</b> covers waste heat recovery and alternative fuels for boilers and kilns. Shared electricity and gas utilities and co-generation facilities also fall into this category.</p> <p><b>Material recovery:</b> involves separation and recovery processes to reclaim specific materials found in the by-product/waste stream for the beneficial use.</p> <p><b>Conversion into a useful product:</b> processing to produce a different useful product.</p> <p><b>Environmentally sound disposal:</b> collective treatment of wastewater to enable its safe disposal.</p>	<p><b>Bilateral:</b> interaction between two parties, either one-way or two-way exchange.</p> <p><b>Service:</b> interaction between one company on one end and two or more on the other end of the synergy.</p> <p><b>Network:</b> – multilateral interaction between more than two parties in both directions</p>

Source: Bossilkov et al. [10].

Berkel [16], a prominent industrial ecologist, found three enabling mechanisms- (1) facilitating structures that encourage collaboration among industries in the same industrial area, (2) operational and contractual arrangements that enable of the necessary resources for implement of IS project and (3) evaluation method that can track and quantify the environmental, social, and economic benefits of IS projects. Another industrial ecologist, Aparisi [11], compiled key factors for the emergence of IS and those are given in Table 3.

In most of the cases there is hardly any pollution control framework adopted by developing nations of the world. Absence of this is one of the key obstacles in adopting industrial symbiosis. Proper

pollution control guidelines would ensure by-product exchange among the participating industries and create economic incentives as well. If the industries are co-located then the transportation costs will be relatively very low which will ultimately encourage exchange of products and vice versa. Long term improvement of the symbiotic network will not be achieved if there is absence of trust among the participating partner organizations. It should be ensured considering the long term development aspects.

Chertow briefly described several elements and analytical tools for industrial symbiosis. She mentioned embedded energy and materials as one of the tools of IS project. In production system, a product requires energy and material which are embedded in that product. By reusing by-products, industrial symbiosis preserves the embedded materials and energy for a longer period within the industrial system. (e. g. by reusing steam or waste heat to produce electricity) Life cycle perspective that is another significant tool of IS project that also need to be uncovered well before uncovering IS projects. Life cycle perspective analyses the total material cycle from virgin material to finished material. With respect to industrial symbiosis a life cycle perspective is helpful in assessing symbiotic opportunities. Cascading involves repeated use of resources such as water or energy. It is a common strategy in implementing industrial symbiosis. It reduces impact of resource extraction, reduce using virgin resource and reduce deposition of waste. That is why Cascading is considered as prerequisite of establishing IS projects. Loop closing means recycling or reusing of resources. It is something like cascading but rather than stepwise it is more circular. Tracking material flow is a key element in industrial symbiosis as it tracks flow of material, water, and energy flow. Then inputs and out puts are analyzed to establish inter firm linkage to ensure efficient use of resources.

**Table 3:** Key factors for the emergence of IS.

Complementary activities	Industrial activities need to be complementary in their needs of resources
Suitable regulatory framework	A suitable pollution control regulatory framework may create the incentives for by-product exchanges
Trust	Trust among the involved partners reduces transaction costs, risk and uncertainty of IS exchanges and is key in the creation of collaborative structures
Reciprocity	Together with trust, reciprocity assures that cooperation is mutually beneficial for all the actors involved
Short mental distance	Short mental distance assures convergence of goals and visions and facilitates communication.
Self-organization/ bottom-up approach	The involvement of key stakeholders, and especially industries, in the process is essential for its further development
Spatial proximity	Transportation costs and other transaction costs are significantly reduced when companies are located in close geographical proximity. Distance may have a discouraging effect on the establishment of collaborative linkages.

Source: Aparisi, (2010) [11].

**Table 4: Concerns, expectations and considerations of stakeholders.**

	Economic	Environmental	Social
Project initiator partners	Local development. Local appeal. Hub of skills and competitiveness. Business longevity. Job preservation and creation.	Environmental impact reduction. Innovation. Regional influence. Meeting of national waste management objectives. Improved environmental quality.	Social responsibility. Local sustainable development. Transparency. Communication. Jobs. Influence. Reduced nuisances.
Project Management team/ Industrial ecology adviser	New business opportunities. Skilled workforce training. Innovation. Identification of complementary businesses. Identification of R&D needs.	Optimized resource and waste management. Calculation of benefit.	Opportunity management. Networking. Ethics. Confidentiality. Communication between stakeholders. Information. Formation of skilled workforce
Participating organizations	Cost reduction. Creation of value. Cost efficiency.	Regulatory compliance. Management cost reduction. Increased recyclability of products. Eco-design.	Retention or creation of commercial relationships. Creation of local partnership. Social responsibility. Corporate image. Positive neighbor relationships.
Service providers	Improved service offerings. New clients. Market sharing and differentiation of products and services. Cost efficiency.	Supply chain optimization. Formalized technical specification.	Retention or creation of commercial relationship. Creation of local partnership. Social responsibility. Fair competition.
Technical experts	Skills and competitiveness hub. Creation of substitutions and mutualization opportunities.	R&D. optimized resource and material management. Innovation. Eco-design.	Recognition of industrial ecology. Ethics. Confidentiality. Understanding the mechanisms of how synergies are carried.
Community	Local benefits. Attracting of complementary businesses to those on site. Regional planning.	Regulatory compliance. Respect for the environment. Ecosystem conservation. Reduced nuisances.	Retention or creation of local jobs. Social acceptability. Social responsibility. Health and safety. Quality of life. Hazard control. Conservation (heritage, landscape, usage etc.)

Source: Centre de transfert technologique en ecologie industrielle [17].



**Table 5: Environmental benefits achieved by different symbiotic networks.**

Name of IS project	Environmental Benefits
Forth Valley (UK)	54,000 tpa sewage sludge diverted from landfill
	5,00000 tpa fly-ash diverted from landfill
	42,000 tpa tyres and RLf diverted from disposal and substituting for 40,000 tpa coal
	11,000 tpa poultry litter diverted from disposal and generating 81 GWh/yr renewable power
Humberside (UK)	183,000 tpa waste material diverted from landfill
Kalundborg (DK)	2.1 million tpa potable water replaced by surface water
	Energy savings equivalent to 30,000 tpa coal and 19,000 tpa oil
	Some 280,000 tpa waste diverted from landfill (fly-ash, scrubber sludge etc) replaced 200,000 tpa gypsum use and 2,800 tpa sulphur use
Moerdijk (NL)	85,000 tpa CO <sub>2</sub> recovered
	3.4 million tonne/yr steam recovery
	0.5 GL/yr water reuse
Rotterdam (NL)	6 MW waste heat recovery for district heating
Londonderry (USA)	18 ML/day reuse of treated waste water as cooling water
Sarnia Lambton (CAN)	Some 175,000 tpa FGD gypsum diverted from landfill
	Energy savings equivalent to 78,000 tpa coal use
Texas (USA)	250,000 tpa waste diverted from landfill (shredder residue and slags)
	18,000 tpa non-ferrus metals recovered
Kawasaki (JAP)	30,000 tpa waste plastics used as blast furnace reductant
	360 tpa waste plastics gasified for ammonia production
	80 tpa solvent recovered
Map Ta Phut (Thailand)	11,800 tpa waste oil reused as fuel and/or for oil paints
	640,000 tpa ferrus chloride/hydrochloric acid recovered
	20,000 tpa scale, dust and refractory material used as cement raw material
Gladstone (AUS)	10,000 tpa bi-product gypsum recovered for reuse
	170,000 tpa CO <sub>2</sub> -eq emission reduction from one cogeneration plant
	9 GL high grade industrial water recovered from treated waste water

Source: (Van Berkel, 2006), \*tpa??, FGD??

## Benefits of industrial symbiosis

Industrial symbiosis is a key tool that can be applied in industrial system as we have stated earlier section of this study. It has several benefits that are found from different studies. The principles of industrial ecology and industrial symbiosis predict that turning waste output from one facility into raw material for another facility will lead to environmental benefits caused by reduced intake of virgin material and/or reduced emissions [6]. Centre de transfert technologique en ecologie industrielle [17], suggested that the following concerns,

expectations and considerations can be achieved through IS practices (Table 4).

It is very much clear that project initiators are highly concerned to reduce environmental impact and to improve the quality of environment whereas community people emphasizing on ecosystem conservation and nuisances reduction. From economic point of view most of the stakeholders are trying to bring cost efficiency apart from local development and regional planning. Retention or creation of local job, social responsibility towards environmental conservation and attaining sustainability in case of local development are considered as social benefit by stakeholders.

**Economic benefit:** Economic benefits for the companies emerging from savings in the cost of inputs and the management of waste and opportunities of revenues generated by the higher values of by-products and waste streams [11]. Some of the economic benefit identified by Van Berkel (2006). In Forth Valley (UK) £1.2 million/yr profit was possible because of reuse of fly-ash. In another IS program, Humberside (UK) economic activity increased £800 million/yr. Another exemplary IS project was Kalundborg (DK) where Total investment US\$ 75 million, total annual savings US\$ 15 million and accumulated savings US\$ 160 million. In Fairfield (USA) US\$ 62 million investment in redevelopment of industrial facilities (incl. soil remediation) and in Gladstone (AUS) Investment in water reclamation plant a \$ 29 million 20% premium price on reclaimed water

**Environmental benefit:** Environmental benefits usually mean reduction of resources due to the reduction in the overall resource needs of the industrial system, reuse and recycling of waste streams and control of pollution [11]. Van Berkel (2006) distinguished environmental, social and economic benefit of different IS projects. Environmental benefit deciphered by Van Berkel (2006) is given in Table 5.

Maximum environmental benefits derived from Forth Valley and Map Ta Phut projects. It is high time to put concentration on industrial symbiosis network and its widespread circulation across the globe.

**Social benefit:** Benefits for the community as a source of new employment, securing existing jobs, improving the local ecosystems or the creation of a cleaner and safer environment [11]. There were not much data available to measure Social benefit. Humberside (UK) Saved 87 jobs Potential for 960 direct jobs and 1,440 indirect jobs (Van Berkel, 2006).

Practical implications of industrial symbiosis from different country perspectives:

Industrial symbiosis can be practiced in different sectors of industrial activities. Industrial symbiosis enhances the establishment of eco-industrial network so that more synergy opportunities can be identified [18]. The different sectors which could be brought under the wide schemes of industrial symbiosis are: (a) waste reduction (b) waste reuse and energy generation (c) materials and products

**Table 6:** Industrial symbiotic initiatives in different countries of the world (cited after Chiu & Yong, 2004) [21].

Country	Participating agency	Location of symbiotic initiatives
Australia	Western Australian Water Corporation, University of Canberra	Shenton Sustainability Park, Synergy Park Brisbane
China	SEPA, UNEP, Dalian University of Technology, Tsinghua University of IE Team, Dalhousie, Indigo, GTZ	Dalian, Yantai, Soo Chow, Tianjin, Guiging, Yixing, Taihu, Shanghai, Chong Yuan, Guiyang and Jiangsu
Philippines	UNDP PRIME and EPIC projects, Yale University, USAEP	Laguna International Industrial Park, Light Industry and Science Park, Carmelray Industrial Park, LIMA, Laguna Technopark, Philippine National Oil Company Petrochem Industrial Park, Clean City Center project (USAID).
Indonesia	Kaiserslautern University	Lingkungan (LIK), Tangerang; Semarang; Industri Sona Maris
India	Kaiserslautern University, ICAST, Technology Exchange Network	Naroda; Tirupur Textile sector; Tamil Nadu tanneries; Calcutta foundries; Tamil Nadu paper/sugar; Bangalore water project; Ankleshwar, Nandeseri, Thane–Belapur.
Malaysia	USAEP	LHT resources linkage.
Japan	UNEP, Tokyo–Osaka–Toyo University, Japanese government	16 ecotowns (e.g. Kitakyushu, Itabashi), Fujisawa, Toyota city.
Korea	NCPC Korea	15 year three-phase Master EIP Plan launched in 2003
Taiwan	ITRI, Taiwan government	Tainan Technology and Industrial Park, Changhua Coastal Industrial Park; CSS II (corporate synergy system II) projects, Hua Lian and Kaohsiung (2003)
Vietnam	Amata developer, USAEP, University of Natural Sciences	Amata (environment management), Hanoi Sai Dong II (feasibility study).
Thailand	GTZ, IEAT	Industrial Estate Authority of Thailand plans (Map Ta Phut, northern region, Amata Nakorn, eastern sea-board, Bang Poo); Samut Prakarn province CPIE project (ADB-funded); Bangkok (Panapanaan).
Singapore	JTC developer, National University of Singapore Architecture Department.	Jurong Island Industrial Park
Sri Lanka	Ministry of Economic and Industrial Development	ADB supported major policy studies in 2002

exchange (d) energy saving etc. A list of practical implications of industrial symbiotic approach for different countries are depicted through Table 6 for better understanding of the scenarios.

### Barriers of industrial symbiosis

Though the industrial symbiosis practices in industries can create benefits in different aspects of economy, environment, and others; successful implementation of it needs to overcome some factors. These factors are the barriers of industrial symbiosis.

**Technological barriers:** IS projects need some technological changes that may bring about forthcoming challenges to the involved industries. Some industries must have to go for some transitional stages and adaptations. Dynamics of industrial systems have to go through some changes too [11]. Bossilkov et al. [10], also mentioned technological changes as one of the barriers. He also questioned about whether with the existing technologies and industry is well enough to start a by-product synergy. Technological barriers were also identified by Brand & Bruijn (1999).

**Economic barriers:** Though IS projects have many benefits both environmental and economic, still many industries find it as virtual because industrial set up for all business industries are not equal. Brand & Bruijn (1999) identified these inequality as economic barrier. For instance, divergences in production cycle varies from industries to industries so it is very much questionable whether by products are feed able to other industries with in the given time period [11]. Another important thing is geographic proximity and it may hinder

by product exchange because of unavailability of low cost transport system [10].

**Informational barriers:** In time of uncovering stage, industries suffocate to establish self-organized industrial symbiosis because they usually lack information about other companies' by-products and waste flow. Chertow [6] found this problem at uncovering stage. Similar result was also found by Fichtner et al. and Aparisi [9,11].

**Absence of trust among organization (Organizational barrier):** Industrial symbiosis programs need several industries to work together and run under several symbiotic exchange. That is why Bossilkov et al. [10], questioned about if the industries are comfortable with working together. Competition among similar industries, lack of environmental consciousness among companies, resistance to change are some reasons why industries are themselves to be considered as barriers [11]. Fichtner et al. [9], identified that Enterprise level barriers are created due to presence of communication related barriers. Intercompany level barriers can also be created when there exists co-operational and inter-connectional barriers.

**Regulatory barriers:** Laws and regulation can be both good and bad for uncovering industrial symbiosis. Regulatory instruments can hinder the exchange of by products or the creation of alliance [11]. Government may be a barrier to synergies through regulatory instruments (e.g. through legislative process). Bossilkov et al. [10], also questioned about whether rules and regulation are encouraging or discouraging industries to work together. Chertow [6], found

importance of government's role in formulating and implementing regulation to start a symbiotic relation. Fichtner et al. [9], addressed it as political barrier.

**Risk and uncertainty:** IS exchanges may generate uncertainties regarding the outcome, performance or cost benefit ratio [11]. Again increased inter-dependency among the industries can increase vulnerability and thus risk of investment increases. And thus vulnerability to context changes [10]. He also questioned whether transportation of a "waste" and use of a by-product lead to increased liability.

### Policy instruments for IS

Industrial symbiosis ensures optimization of resources; as a result a "win- win" situation evolves. Though it has some barriers like trust building and emotional barriers, informational barriers, regulatory barriers, economic barriers, technological barriers, risk and uncertainty, cultural barriers, most of these barriers can be overcome by an interactive policy framework [11].

Policy is a set of actions taken by government body which includes public interest and government strategy. Policy of industrial symbiosis should find out pathways of how principles of industrial symbiosis are incorporated into national policy and what should be their characteristics of national policy and management strategies. Four concepts of Policy Science (policy implementation, policy diffusion, policy transfer, and policy translation) are often used to explain the dissemination phenomena. Aparisi [11] discussed the components of policy of Industrial Symbiosis under three main levels of analysis. The first level deals with institutional framework that influences the political decision-making process, knowledge, values and principles. The second level and third level respectively refers to the regulations and promotion of IS projects. Policy implementation discuss on executing the objectives of a policy usually in the top-down hierarchy direction. Policy transfer and policy diffusion are both used to explain ways of how knowledge about policies used across time or space in the development of policies elsewhere, while the latter one emphasizes on the convergence of policy. Policy approaches needs to disseminate at all levels of stakeholders. It commonly involves: (1) setting goals, objectives, (2) developing instruments of regulatory, economic and informational/ voluntary nature [13]. They

also analyzed policy development at three levels: (1) Supra- national level, (2) national policies and (3) Sub national policies. Coordinating organizations at supra national levels arrange conventions or programs to mitigate transnational challenges. Beside these, national governments works on social, environmental and social context and sometimes incorporate with supra national level. Lastly sub-national policy interventions are formed at region, state or municipality but aligned same with national and supra national policy context [13] (Figure 1).

Chertow [6], proposed three potential policy ideas of industrial symbiosis at uncovering stage. These are to:

Bring to light kernels of co-operative activity that are still hidden: Business managers know about their byproducts, but lack of access to information about their neighboring industry hinders the potential role of material exchange. Mapping flows of heavy industries can uncover many kernels of exchange and it should be widely dispersed and should include smaller and less industrial companies.

Assist the kernels that are taking shape: Where a kernel exists and involves two or three firms to facilitate an industrial symbiosis, they also need assistance to form a distinct shape. Further query should be continued to discover new trading ideas.

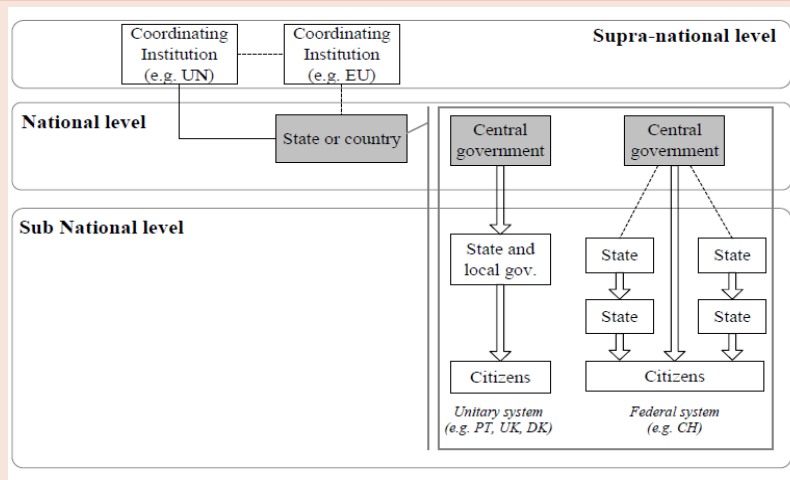
Provide incentives to catalyze new kernels by identifying "Precursors to symbiosis": Provide incentives to catalyze new kernels by identifying "precursors to symbiosis": In industrial system there are some common environmentally related activities those can be seen as precursors to symbiosis. Simply precursors to symbiosis can be defined as a resource exchange with the public goods component but it will involve only one or two firms or other organizations. Examples of such precursors to symbiosis are the projects that share resources involving: (1) Landfill gas (2) cogeneration (3) waste water reuse.

Eilering & Vermeulen [19], discussed (five) policy instruments for IS projects which may differ in terms of enforceability. Legislation was the first and foremost policy instrument considered by them. Other elements are financial incentives, park management agreement, input and exchange of knowledge and experience and promotion and acquisition of new or existing industrial parks are also mentioned as important policy instruments. The identification of good anchor

**Table 7:** Suggested policy framework under different themes.

Themes	Including policy instruments
<b>An integrated framework to support the greening of industries</b>	Development of national strategies, institutional integration, policy implementation, and the potential role of transition management in green industries.
<b>Creating an enabling environment</b>	Government influence to support the greening of industries measures include the removal of harmful subsidies green procurement, financial support structure harnessing the benefits of globalization, trade agreement resource co-efficient infrastructures, and developing the skill necessary to support the greening of a industries.
<b>Supporting an industry led initiatives</b>	Government supported industry led initiative to promote efficiencies and environmental improvement. Eco level and certification, life-cycle analysis, green supply chain, extended producer responsibility, raising awareness, and capacity development.
<b>Harnessing environmental technologies</b>	Role of government in facilitating the creation and diffusion of environmental technologies, emphasizing the importance of technical capacity, building a science base financing technology development, technology diffusion, science networks, collaboration, and infrastructure.
<b>promote the greening of industries</b>	Influence of government policy instruments to promote sustainable production and sound environmental management.

Source: (UNIDO, 2011) [22].



**Figure 1:** Policy formulation network for IS network( adapted from Costa *et al.*, 2010) [23].

tenants is also a successful policy instruments for promoting the development of industrial symbiosis. It would allow for the creation of policy targeted at the correct industries and companies, allowing for the creation of appropriate policy, without the challenges of being applied universally, which has the potential to have significant environmental impact [1]. Other than this, industrial firms play a leading role in environmental management and policy. They mainly focus on (i) optimization of voluntary approaches that can be effective in bringing about environmental improvement, and (ii) reliance on industrial firms as the locus of technological expertise, which in turn, is seen as crucial to strategies emphasizing design for environment [20]. Besides, Environment laws and regulations can be introduced to encourage industry to adopt environmental technology and form symbiotic linkages. Industrial symbiosis became more economically feasible under the law. Environment taxes on certain raw resources foster the development of synergies to consume fewer raw materials [14]. Technology, business case and license to operate or legislation, are three success factors for symbiotic synergies. A sustainable policy framework can foster these elements to make a compatible synergy [10]. In a report of United Nations Industrial development Organization provided a policy framework were viewed under five themes (Table 7).

## Conclusion

Concept of industrial symbiosis is borrowed from biological concept where two or more industries form a cluster to share their by-products for their own betterment. It is now considered as one of the sustainable instruments that will sure to reign future industrial mechanism. Industrial symbiosis brings about sustainability by initiating the circular flow systems within the industrial sector rather age old linear flow system. This technology is also known as cleaner technology where it aims to achieve resource efficiency by reducing usage of virgin material. Reduction of usage of virgin material also reduces waste generation. Empirical research has learnt a lot about the phenomenon of business entities from research of last 25 years. The focus of the article was only to accumulate determinants, approaches,

benefits and barriers, and essential policy instruments suggested and documented in empirical research. Two approaches of emergence of industrial symbiosis can be easily distinguished. Some industries of proximate distance come forward to share their by-product within them and this approach is known as spontaneous approach while second one is rather planned. But spontaneous and planned symbiotic networks had to go through some difficulties like technological barrier, informational barrier, lacking of trust, economic barriers at their uncovering stage. Future research is needed to find out solutions of the existing barrier. Empirical research suggested that both regulatory body and the industrial entities are responsible to search possible pathways that will hopefully minimize barriers. Again some of already established symbiotic networks are economically and environmentally successful. Factors beyond these success story needs to be replicated and barriers that hindered the growth needs to be resolved or exempted. Policy formulation is one of the possible solutions and policy maker needs to work simultaneously at regional, national and supra international level with some standard procedure. One of such example is NISP which facilitated industrial symbiosis pilot programme in the United Kingdom in 2004 through which extra landfill tax was imposed to make the industries recycle their waste from landfill to produce raw material. Finally, authors hope that this article will help public and private actors to undertake appropriate decision in respective field and provide many opportunities to the potential industries opt for symbiotic network.

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