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**Hanmin Huang** studied for his “Master of Studies in Sustainability Leadership” at Cambridge from 2013-2015. The following article is based on his dissertation, entitled “Dynamic Mechanism Leading to the Formation and Development of Industrial Symbioses: An Empirical Study on Industrial Symbioses of the Sugar Industry in Chongzuo City, China.”

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Population and consumers’ demand for resources (overall and per capita) are on the rise (The Royal Society, 2012, p.62; WBCSD, 2014), but we live on a planet with finite resources (Evans and Bocken, 2014). The sustainability challenge for us is how to produce sufficient goods to satisfy the need of an ever growing population with the finite resources of our planet while keeping the earth intact for future generations. In response to this sustainability challenge, circular economy practices have emerged. The term “circular economy” has been popularized by the Ellen MacArthur Foundation (2014), and has been adopted in Europe and China, generally used to mean “to reduce, to reuse and to recycle waste” for enhancing social and environmental well-being. It is a promising approach to help reduce global sustainability pressures (World Bank, 2009; European Commission, 2014 cited in Bocken et al., 2015). Industrial symbiosis is a concrete industry practice of circular economy. In Bocken *et al.* (2015, p.13), industrial symbiosis is defined as “a process-orientated solution, concerned with using residual outputs from one [industrial] process as feedstock.” Currently, however, there are still too many obstacles for practising industrial symbioses (Chertow, 2012; Boons *et al.*, 2014). It remains a research problem as to what might make or break industrial symbiosis formation and development and what can be done to facilitate such development. Unfortunately, literature reviews have found that there are research gaps in understanding and dealing with this problem (Chertow, 2012; Boons *et al.*, 2011). Firstly, most of the studies are on the formation of industrial symbiosis networks (or “Type 3-5” in Chertow, 2000, p.321), paying little attention to internal symbioses (or “Type 1-2” in Chertow, 2000, p.321) (Short et al., 2014). Secondly, there is a lack of procedural research (Cohen-Rosenthal, 2000; Boons et al., 2014) examining processes, dynamics and causes (underlying causal structures) of industrial symbiosis formation. Lastly, existing research focuses primarily on external processes and contextual factors, but not on factors, processes and dynamics inside enterprises which create and develop industrial symbioses

**Research scope, research objective and research questions:**

To help close the research gaps, the present researcher studied in 2014 the formation and development of internal symbioses in four sugar refineries in Chongzuo City, China. This choice is appropriate for several reasons. One reason is that internal symbioses are still the hallmark of the sugar industry in the city; and indeed, internal symbioses seem to be very prevalent in sugar industry in general. Yet there is still

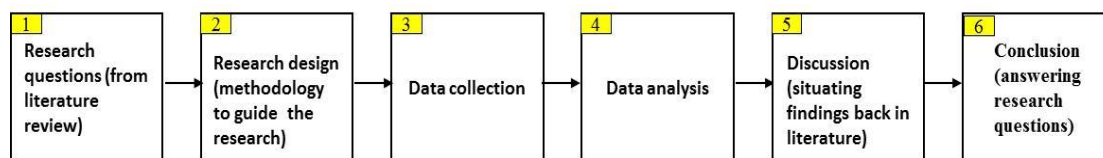
insufficient research on such internal symbioses (Short *et al.*, 2014). Secondly, as an underdeveloped city, Chongzuo City has been undergoing socio-economic transformation since the 1980s when China began to open to the outside world. Its sugar industry is under threat due to the high cost of sugarcane farming and so sugar refineries have had to find ways to utilize sugar production by-products. The objective of this empirical study was to identify the causes that have led to the emergence and evolution of these sugar industrial symbioses in their socio-economic context in Chongzuo City, China. In order to achieve this objective, research activities were carried out to find the answers to the following research questions:

- How did internal industrial symbioses in Chongzuo City’s sugar industry develop?
- Why were they able to develop? In other words, what were the causes for
- development of these sugar industrial symbioses?

### Research methodology:

The present empirical study was conducted (with data analysed) at the value chain level and the firm level. The project was carried out in six phases as shown below:

Figure: Processes of the present research



In term of research methodology, the present research adopted “critical realism” as its ontological view and “critical interpretivism” as its epistemological stand. The present research followed the qualitative research strategy, which is appropriate for conducting research as to how and why industrial symbioses emerged and evolved in Chongzuo City, China (Miles and Huberman,1994). It adopted a “multiple-case embedded design” and used semi-structured interviews and archival research methods to collect empirical data on the city’s sugar industrial symbioses. These data were analysed according to qualitative data analysis processes and methods recommended by Miles and Huberman (1994), and since the present research is procedural in nature, its data presentation and analysis followed methods recommended for procedural research by Griffin (1993) and Boons et al. (2014).

### Key Research Findings:

The first finding is that market incidents, business incidents, learning, innovation and capability building incidents are three most important antecedents (or activities) that affected the formation and evolution of sugar industrial symbioses. The first two antecedents are also found in the existing literature (Ehrenfeld and Gertler, 1997; Desrochers, 2004). However, the third antecedent (corporate learning and innovation activity) is seldom mentioned in existing literature on industrial symbioses, although it is often found in literature on firm growth.

The second finding is that the present study has no conclusive support for Porter’s Hypothesis (Porter, 1991; and C. van der Linde, 1995). The present study has found that enforcement of national and local environmental regulations seemed to have had an indeterminate impact on sugar industrial symbiosis formation and development: it could be an advantage in some situations but a disadvantage in others. This finding is in line with those from other studies (Broberg et al., 2013; Rexhauser and Rammer, 2014).

The third finding from the present research is that there are four external processes and two internal processes underlying industrial symbioses: social change, institutional change, technological progress, business development, organizational learning and innovation. One of these processes has also been found by Boons et al. (2011), Boons et al. (2014) and Spekkink (2013): institutional change process. However, the present study has found many more external transformation processes working together to enable formation and evolution of the city's sugar industrial symbioses (Norgaard, 1984; Hoffman, 2003). Furthermore, contrasting studies by Boons et al. (2014) and Spekkink (2013), the present study has found that the internal learning process played a more important role than the social networking processes found in studies by those scholars. This is perhaps because industrial symbioses under study were not external symbioses (industrial symbioses network) but internal symbioses (Type 1-2 in Chertow, 2000).

The fourth finding is that the success or failure of industrial symbioses in case companies seemed to be the result of interaction (dynamics) between institutional pressure for environmental protection, market forces related to sugar and its co-products, corporate motivation to grow and outcome of the corporate learning and innovation process. This is different from the findings of some scholars who believe that factors and processes, not dynamics thereof, determined success or failure of industrial symbiosis formation and development (Teh et al., 2013).

### **Conclusions from the search:**

From the empirical findings of the present study, as summarized in the above session, and the process theory developed thereof, it seems plausible to draw the following conclusions to answer the research questions at the beginning of the present research. In the following, conclusions are made to answer firstly the how-question and then the why-question.

The first research question is: how did internal industrial symbioses in Chongzuo City's sugar industry develop? The following three conclusions provide answer to this research question.

Research conclusion 1: Industrial symbioses of the sugar industry in Chongzuo City (mainly internal symbioses) were initiated and sustained by various interacting social processes and organizational processes: social change, technological progress, institutional transformation, business development, organizational learning and innovation.

Research conclusion 2: The above processes interacted to form a dynamic mechanism producing forces which shaped internal industrial symbioses development in the sugar refineries under study. Some of these forces were driving forces: corporate desire to grow, demand for sugar by-products and social (institutional) pressure for environmental protection; others were enabling forces: technological advances and corporate organizational learning and innovation. According to the research findings, corporate organizational learning and innovation is the most important enabling force of industrial symbiosis development.

Research conclusion 3: When the driving forces and enabling force described in "Research conclusion 2" were both positive, the dynamics led to emergence and development of industrial symbioses; by contrast, negative forces from the dynamic mechanism stifled or even reduced industrial symbioses.

The other research questions of the present research are: why were internal industrial symbioses in Chongzuo City's sugar industry able to develop? In other words, what were the causes for development of these sugar industrial symbioses? The following conclusion provides the answer to these research questions.

Research conclusion 4: Some sugar refineries under study were able to grow their business and corresponding industrial symbioses, because they had strong desire to grow and were successful in learning and innovating sustainable business models to meet both market demands and environmental requirements. The causes of successful formation and development of industrial symbioses in the city's sugar industry lay, not in indeterminate influencing factors (various antecedents), but in the following positive driving forces (dynamics): aligned interactions between increasing corporate desire to grow, rising demand for sugar by-products, expanding social (institutional) pressure for environmental protection, and highly effective corporate organizational learning and innovation. This argument is the thesis of the present dissertation.

### **Research implications for policy making and management decision making:**

From the findings and conclusions of the present research, several implications can be drawn for future policy making and management decision making. The Chongzuo City government should

- Attract more market brokerage firms or market agents to promote active resource allocation by the market in its sugar industry in order to create a more vibrant market for sugar by-products such as yeast and food seasoning powder.
- Enforce environmental protection laws and regulations to give sugar refineries pressure to innovate, which may move them towards sustainable development (Porter, 1991; Porter and C. van der Linde, 1995).
- Improve the social environment (e.g., building better schools for children of engineers in their sugar refineries) so as to attract industrial talents, particularly, those in sugar industrial symbioses.
- Facilitate the flow of sustainability knowledge between companies, universities and other research institutions through various means such as encouraging technology consultants to operate in the city.

As for the sugar refineries, they should create an open and stimulating organizational environment for learning and innovation on sustainable industrial technology, because success of industrial symbioses projects very much depends on the effectiveness of corporate learning and collaborative research, as the present empirical study has found it out.

### **Future research directions:**

Considering the contributions and limitations of the present research, it seems appropriate to suggest two directions for future research. If possible, more procedural studies should be carried out in greater depth, using a greater number of cases, to see if the findings, theory, model and arguments of the present study can be confirmed, modified or rejected. In particular, it would be interesting to know if sugar refineries in other settings also see corporate learning and innovation process as an extremely vital process that determines success or failure of their industrial symbioses. Secondly, the process theory and system dynamic model developed in the present research can be used as a stepping stone towards building an agent-based simulation model to see how and why industrial symbioses evolve, as well as whether evolutionary steady state (ESS) characterized by Pareto eco-efficiency exists (Mathew and Tan, 2011) and if so, under what conditions. This could be a very difficult, but exciting, future research direction which may expand our knowledge of industrial symbiosis formation and development in the sugar industry.