From Refining Sugar to Growing Tomatoes: Industrial Ecology and Business Model Evolution

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Keywords:

Business model innovation, Competitive advantage, Industrial symbiosis, Value creation, Sustainability

Summary

This article seeks to advance the understanding of the relationship between industrial ecology and business model innovation for sustainability as a means and driver of new value creation and competitive advantage by expanding understanding of industrial symbiosis and internal symbiosis. This is explored through the case study of British Sugar, which at the time of writing, is the UK's largest sugar producer by market share. Over the past three decades the company has systematically sought opportunities to turn waste streams and emissions from their core production processes into useful and positive inputs to new product lines. Their core business is still sugar, but the business model has evolved to offer a broad range of additional synergistic and profitable product lines including animal feed, electricity, tomatoes, and bioethanol. The research explores the temporal dimension of dynamic business model innovation, framing it in the context of a continuous evolutionary process rather than a discrete design activity. The case will be of interest as an additional contribution to the growing literature on industrial symbiosis; in offering an approach for linking the themes of industrial ecology literature and sustainable business model innovation more concretely in research and practice; and, by presenting the case as an evolutionary innovation process, the article furthers the emerging literature on business model innovation for sustainability.

1 Introduction

Many companies use industrial ecology principles to convert negative environmental externalities associated with production waste into positive value both for the environment and firm competitiveness by enhancing resource productivity and closing material loops. *Industrial symbiosis* is the name of the sub-section of the broader field of industrial ecology that pays careful attention to networked resource exchanges. Industrial symbiosis has also been defined as an "inclusive descriptor" for the myriad ways industrial outputs are exchanged "that, in the absence of a customer, would normally be discharged to the environment and hence become treated as environmental externalities" (Chertow & Ehrenfeld 2012, p.13). The goal of reusing networked resources including water, energy, and materials may occur a) within a single company or industry or b) across multiple firms in traditionally separate industries.

The objectives of industrial ecology-related business, then, appear to be at least somewhat aligned with those of 'sustainable business models' – defined by Lüdeke-Freund (2010) as "*business models that create competitive advantage through delivering superior customer value while contributing to sustainable development of the company, the natural environment and society*" (p.17). The literature, however, is still vague on the connection between industrial ecology and competitiveness. More than 15 years ago, for example strategy experts Esty & Porter (1998) explored industrial ecology at the firm-level and observed that although industrial ecology may contribute to competitiveness through enhanced resource productivity, the focus of industrial ecology on resource flows could actually detract from a focus on competitiveness in other key corporate performance areas such as employee productivity or competitive strategy. On the other hand, Ehrenfeld & Gertler (1997) declared during the same time period that, in general, the industrial symbiosis relationships they studied were not inherently different from traditional supplier-customer relationships.

More recent studies recognize the potential of industrial symbiosis to inform strategic business decisions and business model innovation more fundamentally (e.g., Zhu et al. 2007; Laybourn & Morissey 2009; Pauli 2010). We argue that bringing together more nuanced understanding of industrial symbiosis with the progress being made in the study of sustainable business models would serve as a promising bridge between symbiosis as an ecological term and business models as a financially related expression. This combination would enable a shift beyond resource productivity and process innovation towards a broader consideration of business opportunities and new forms of value creation. Such broader change in the value creating logic of the firm is at the core of business model innovation theory. In this research, the case of British Sugar is presented to provide an example of business model innovation which builds on industrial ecology principles.

2 Business models and sustainability

The following sections introduce the literature on business model innovation and the potential linkage with the existing literature on industrial ecology and industrial symbiosis.

2.2 Business models

A business model in simple terms explains "*how a firm does business*" (Magretta 2002), articulating the logic of how a firm creates and delivers value for its customers and how the firm captures value for itself (Osterwalder et al. 2005). Interest in the business model concept has risen dramatically over the past decade and it is now increasingly recognized as an important key to business success, and may even represent a new unit of analysis for the firm (Teece 2010).

The literature presents various perspectives on what constitutes a business model (Chesbrough 2007; Richardson 2008; Teece 2010). One of the more widely cited business model frameworks is presented by Osterwalder & Pigneur (2005), describing the business model as made up of nine elements as shown in Figure 1. Richardson (2008) consolidates these under three themes: *value proposition, value creation and delivery, and value capture* (Figure 1).

Value Proposition	**Value Creation & Delivery Systems**	**Value Capture Mechanisms**
1) Product/service offerings 2) Customer segments, and 3) Customer relationships (*What value is provided and to whom)*	4) Activities, 5) Resources, 6) Partnerships and suppliers, 7) Distribution channels. (*How value is provided)*	8) Cost structure, 9) Revenue streams *(How the company makes money from providing value)*

Figure 1. A business model framework (based on Osterwalder & Pigneur 2005; Richardson 2008).

2.2 Business models for sustainability

How business models can facilitate sustainability has had a resurgence in contemporary research (Porter & Kramer 2011; Schaltegger et al. 2012; Bocken et al. 2013; Boons & Lüdeke-Freund 2013; Bocken et al. 2014). The literature suggests that while current approaches to sustainability such as efficiency improvements, cleaner production, and corporate social responsibility (CSR) are important in reducing un-sustainability they do not, on their own, deliver sustainability. A more systemic approach is necessary that better aligns the core business purpose with the requirements for long-term sustainability. Innovation in the business model itself potentially offers this opportunity to integrate sustainability considerations far more fully into the purpose of the firm.

Business model innovation for sustainability is a growing area of literature, yet despite theoretical contributions, there is still a relatively limited understanding of how it might be undertaken, or what sustainable business models might or should even look like in practice. One notable contribution is the recent OECD report on green business models (Beltramello et al. 2013); however, this report focuses more on environmental aspects than sustainability broadly. Others, such as Yunus et al. (2010) have developed the role of social enterprise as a means to delivering social sustainability. Wells (2013) presents a broader view of business model innovation in the industrial context. Similarly, Bocken et al. (2014) based on a comprehensive literature review present a set of *business model archetypes*, seeking to provide a unified framework bringing together the numerous disparate themes in the sustainability literature under the umbrella topic of business model innovation. The archetypes presented represent the underlying mechanisms for delivering sustainability through the business model. These archetypes are: *Maximize material and energy efficiency; Create value from waste; Substitute with renewables and natural processes; Deliver functionality rather than ownership; Adopt a stewardship role; Encourage sufficiency; Repurpose for society/environment;* and *Develop scale up solutions*.

2.3 Industrial ecology and creating value from waste

The '*Create value from waste'* archetype (Bocken et al. 2014) reflects one of the themes of industrial ecology – that of seeking to reduce the environmental impact of industry, demand for virgin resources, and waste to landfill, by eliminating the concept of 'waste' through approaches such as closing material loops and turning waste streams into useful and valuable input to other production processes or products, and optimizing use of under-utilized capacity. It parallels the natural world, where the concept of waste does not really exist because all 'waste' products become feedstock for another natural kingdom (Lambert 2002; Gibbs & Deutz 2007). This concept also forms the underlying premise of *industrial symbiosis*.

In the language of business model innovation, the archetype 'create value from waste' describes how a company might reconceive its value proposition by identifying and creating new value from what is currently perceived as waste through a restructuring or re-conception of the value creation and delivery system. The firm captures value for itself by seeking new mechanisms to monetize the customer and/or public benefits associated with the new value proposition (Lüdeke-Freund 2010; Porter & Kramer 2011) as shown in Figure 2.

Value proposition	**Value creation & delivery**	**Value capture**
The concept of 'waste' is eliminated by turning existing waste streams into useful and valuable input to other production.	Activities and partnerships to eliminate life cycle waste, close material loops, and make best use of under-utilized capacity. Introduction of new partnerships (e.g. recycling firms), potentially across industries, to capture and transfer waste streams.	Economic and environmental costs are reduced through reusing material, and turning waste into value. Positive contribution to society and environment through reduced footprint, reduced waste, and reduced virgin materials use.

Figure 2. Business model archetype 'create value from waste' (Bocken et al. 2014).

Material exchanges provide a useful means of creating value from waste. Five types of material exchanges have been defined by Chertow (2000): 1. Waste passed on by businesses to operations such as scrap dealers for recycling (and not regarded as symbiosis); 2. Within a facility, firm, or organization; 3. Among co-located firms in an Eco-Industrial Park; 4. Among local firms not co-located; and 5. Among firms organized "virtually" across a broader region. The industrial ecology literature involving multiple companies (that is, Chertow's types 3, 4 and 5) is extensive, but there is less about type 2, which occurs primarily within the boundaries of one organization and has been dubbed "internal symbiosis" by industrial ecology pioneer Ernest Lowe and described more fully through an example in the sugar industry in China discussed below (Zhu et al. 2007). Nemerow (1995) outlined 15 models for industries such as pulp and paper or petroleum complexes that can or do rely on extensive by-product utilization with users of by-products that may be internal or within the same supply chain.

Highly relevant to the case study in this article is an initiative by the Guitang Group, a sugar producer in China which set up new processing facilities to utilize by-products as a route to increasing employment and profitability (Zhu et al. 2007). The original state-owned company was established as a sugar refinery incorporating an alcohol production facility to use the molasses by-product. Later, the company added paper mills to use the bagasse (waste organic pulp), followed by cement and fertiliser production operations, sharing waste energy and waste compounds in a symbiotic manner. Benefits included not only increased revenues but significant improvements in product quality, operational efficiencies and environmental performance. Following these successes from internal symbiosis, a network of external symbiosis relationships was developed with government, customers, competitors and suppliers.

Although the China State Environmental Protection Agency promoted the Guitang Group initiative for its strong economic and environmental performance, such projects have not become widespread. This was attributed by Zhu et al. (2007) mainly to firms not being willing to deviate from established business models, nor diversify from their 'core competences'. Erkman & Ramaswamy (2003) present a similar case combining internal and external symbiosis in India – Seshasayee Paper and Boards Ltd. In this case the mill owners, facing a shortage of wood for pulping, invested in a new sugar refining subsidiary to develop a source of fibrous waste from sugar cane (known in the industry as bagasse) to obtain raw material for paper making. This was subsequently extended through an external relationship with an alcohol refinery and a methane generator to use the waste molasses from the sugar refinery. Similar reluctance to grow single-firm symbiosis to include other actors, however, was also noted in India (Erkman & Ramaswamy 2003).

2.4 Dynamics of industrial ecology and business model innovation

Innovation is a primary consideration within the business model literature. Zott & Amit's (2010) view of the business model as an inter-connected system of activities suggests innovation should take the form of *adding new activities*; *linking activities in novel ways; and changing which parties perform an activity*. Schaltegger et al. (2012), focussing specifically on sustainability, propose a business model innovation typology of '*defensive*', '*accommodative*', and '*proactive*' innovations. Defensive strategies are minor incremental adjustments to protect the current business model, focusing on risk and cost reduction (only partially representative of business model innovation, and perhaps most closely aligned with the perceptions of industrial ecology as process innovation). Accommodative strategies are improvements to the business model (e.g. cost and reputation orientation); and proactive strategies concern the redesign of the core business logic of the firm (changing many of the elements of the business model).

Massa & Tucci (2013) suggest that business model innovation should be conceived as a dynamic and temporal process of continuous experimentation and levels of maturity. Davidson (1999) proposes three phases of business transformation: phase 1 being a structured approach to cost reduction and productivity re-engineering efforts; phase 2 builds on new infrastructure and capabilities to enhance and extend the original business; and phase 3 redefines it to create new businesses. Recent work by Boons et al. (2011) similarly describe the dynamics of industrial symbiosis as a "process" illustrating commonality between the literature streams. However, to date, the literature presents little practical exploration of such evolutionary processes in business model innovation for sustainability.

3 Methodology

The objective of this article is to advance the relationship between industrial ecology and business model innovation as a means and driver of new value creation and competitive advantage by expanding understanding of industrial symbiosis and internal symbiosis. This article seeks to develop a bridge between the industrial ecology literature and the emerging sustainable business model innovation literature to enable better conceptualization of the potential role of industrial ecology within the business model context, and contribute to understanding of the process of business model innovation itself. Methodologically, it draws on the single case study of British Sugar's factory in Wissington, Norfolk, UK.

British Sugar has been a major UK sugar producer since 1925, processing locally grown sugar beet into a range of sugars and syrups for supply to the food and beverage market. British Sugar is the UK's only processor of sugar beet, processing approximately 7.5million – 8.5million tonnes of beet to produce more than 1 million tonnes of sugar products in total per year across its four sites in the UK. British Sugar represent about 85% of the UK sugar production (IBISWorld 2013b), and approximately 55% of total UK demand for sugar (the balance being processed locally from imported sugar cane, or imported directly as sugar products). In 1991 British Sugar was acquired by AB Sugar, which is one of the world's largest sugar producers, and is a wholly owned subsidiary of Associated British Foods, a diversified international food, ingredients and retail group. The focus of this case study is British Sugar's factory in Wissington, which is the world's largest beet sugar refinery, employing 270 full time and 85 seasonal staff and producing over 420,000 tonnes of sugar products annually.

The case was selected because it represents a good example of business model evolution implemented through a focus on industrial ecology principles including several instances of internal symbiosis and a growing number of instances of "over the fence" external symbiosis with additional companies. Like the Guitang Group in China, British Sugar has modified and extended its business model over a period of decades to utilize internal waste streams to create new co-products and internalize environmental externalities (i.e. waste streams) within their business model. Archival data and access to key personnel at the company was a key factor in selection of the case as it enabled a rich study of the innovation process to be undertaken.

Five separate semi-structured interviews were conducted: two with the head of sustainability and three with the head of technology of AB Sugar (representing senior decision makers of the British Sugar factory). These were conducted in face-to-face and telephone meetings between October 2011 and May 2013. The initial interviews were structured around theoretical frameworks from the literature, and subsequent interviews progressively explored emerging themes from the research and analysis work. The interviews were supported with a review of secondary literature and market data available in the public domain. During the course of the case study preliminary findings were submitted to the interviewees and circulated to other key staff within British Sugar for further review and comment to confirm accuracy and understanding, and supplement the interview material. The case study explored the following themes:

a) Journey towards sustainability, the scope of the business innovations from an IE perspective, and the planning and evolutionary process (utilising theoretical frameworks based on Davidson (1999); Osterwalder & Pigneur (2005); Richardson (2008), and use of road-mapping techniques (Phaal et al. 2011);
b) Drivers, antecedents, and enabling mechanisms for innovation (Boons et al. 2011);
c) Competitive advantage through business growth and diversification;
d) Ecological outcomes in terms of energy and water use, waste reduction, CO_2 emissions reduction, and agricultural land utilization.

Various industrial ecology approaches have been employed by the company over the period considered. However, the primary focus of this case study and the analysis and discussion presented in this article, is on those aspects that represent business model innovation and to track them over time. The case is then analysed in the context of the business model literature and frameworks presented therein to explore the evolution of the business model and the role of industrial ecology within this process.

4 British Sugar

The following sections introduce the British Sugar case.

4.1 Context – An industry under threat

British Sugar's journey towards "sustainability" described in this case study covers the period from 1985 to the present. A significant catalyst for change was the 1991aquisition of British sugar by AB Sugar, which brought new management and greater focus on business development and growth. At the time British Sugar was operating in a highly protected industry sector, enjoying restrictive trade agreements and a protective agricultural quota and subsidy system. It was recognized, however, that changes in the European Union (EU) Common Agricultural Policy coupled with increasingly open global trade agreements would progressively open the UK market up to competition. (The quota system is expected to be completely removed by 2017, but is being reduced in stages). This, combined with the expanded production of low-cost sugar derived not from beets but from sugar cane in developing nations, represented a significant threat to the future of British Sugar. In addition, with the core sugar business constrained by the existing quota system, the company was prevented from further growth in its sugar business. Other important external factors influencing the business development over this period were increasing supply-chain risks associated with the growers of sugar beet which necessitated efforts to support and incentivize the grower community, and emerging legislation related to renewable transportation fuels that created new UK markets for biofuels derived from agricultural crops.

Responding to the above business drivers, British Sugar embarked on an incremental process of innovation to deliver efficiency and productivity improvements to reduce costs and, at the same time, develop new product lines to enhance the company's competitive position in the market as described more fully in the following sections. Creating value from waste has been a key objective throughout, although in the initial stages of this journey environmental concern was not an explicit management objective. The innovation path has built incrementally on the existing core production of sugar products at the Wissington site.

4.2 Sugar production process and related co-product streams

Modern sugar production is undertaken in specialized large-scale process facilities. Figure 3 illustrates the sugar production process at Wissington. To begin, the factory takes in locally grown sugar beet, washes and cleans it, slices it, and then puts it into a diffusion process where the beet is mixed with hot water to extract sugar. The resulting liquid is passed through a purification process where impurities are removed through precipitation, creating 'thin juice', which then goes into an evaporation process where water is boiled off in a series of evaporator vessels to reduce the water content. The resulting 'thick juice' goes through a crystallization process where it is boiled under vacuum and centrifuged to produce sugar crystals. The process is highly energy intensive requiring large amounts of heat at each stage. The process yields various liquids, syrups, and sugars including granulated sugar and caster sugar (super fine sugar produced by screening). These are bagged, or distributed via bulk transportation for use in the food and beverage markets.

Initially, the company produced only sugar products, whereas today it produces a diverse range of co-products (defined as saleable products that contribute financially to the business by making use of the waste streams or by-products of the primary sugar production processes) for various markets. These include: topsoil for landscaping, aggregate for the building trade, animal feed and animal feed supplements for livestock growers, soil conditioner for the agricultural sector, betaine for the cosmetics industry, tomatoes for the retail food sector, bioethanol for transportation fuel, liquefied CO_2 for the soft drinks industry, and export of electricity to the national grid. Figure 3 illustrates the core sugar production line and the network of new co-product lines that have been developed on the Wissington site by utilizing the waste material and energy streams from the sugar process.

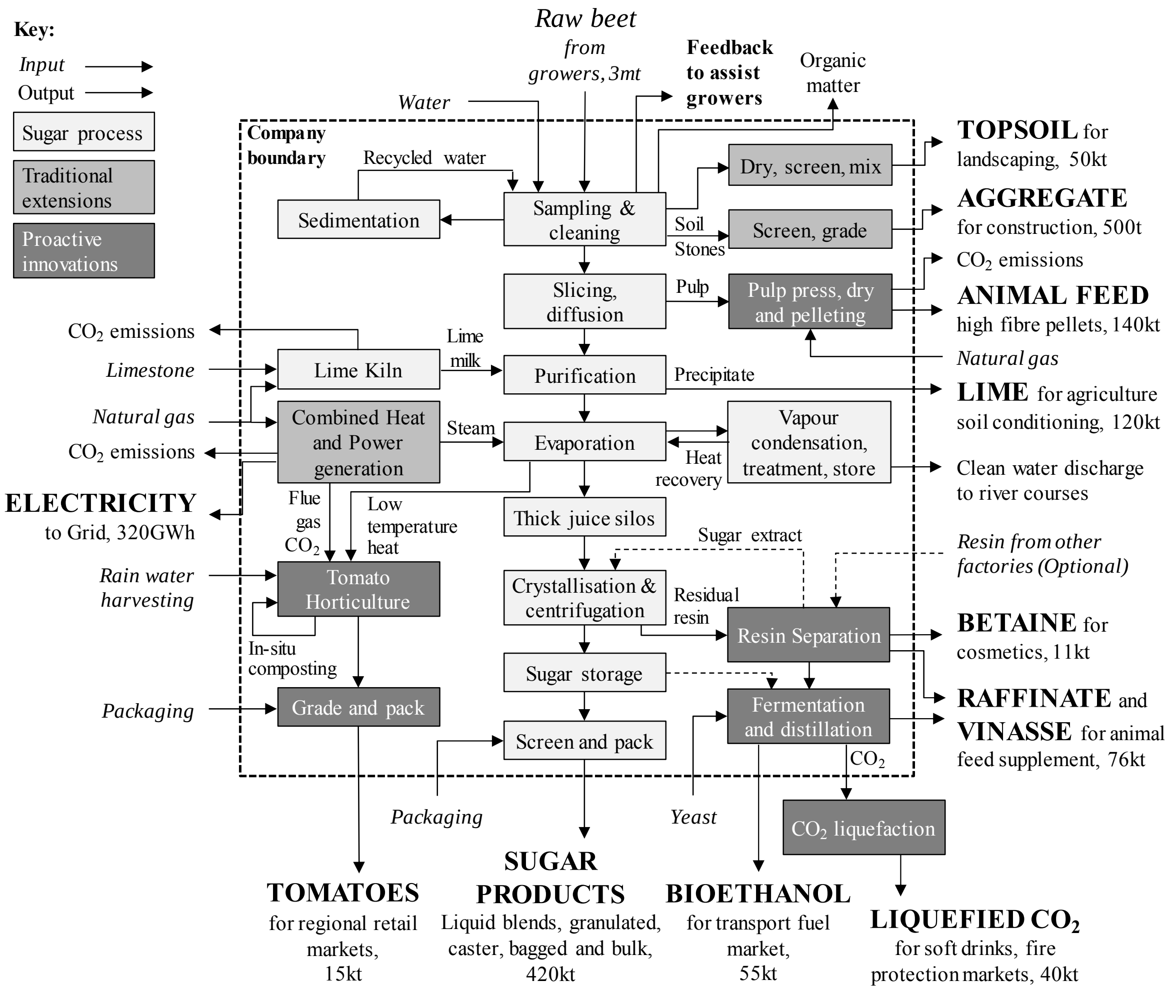

Figure 3. Schematic of symbiotic co-product lines at the British Sugar Wissington factory (figures in tonnes).

4.3 Business model evolution

The innovations in British Sugar presented in this article span nearly three decades. Figure 4 applies road-mapping techniques (Phaal et al. 2011) to illustrate this evolutionary path from the mid-1980s to the present. The efficiency and productivity improvements and development of new co-product lines over the period are shown relative to the key external factors driving change. The figure identifies the modifications in each component of the business model framework (the incremental extensions to the value creation and delivery system, the extended value proposition, and the new revenue streams capturing value) associated with the each business initiative. The road map highlights some path dependencies in the development of additional co-product lines, and in the case of tomato growing (horticulture) shows three phases of expansion. Initial innovations were largely internal to British Sugar, but as the business evolved external partnerships were developed to extend the business further – with Air Liquide to produce liquefied CO_2, and an external joint venture, Vivergo, to build a new bio-refinery in Hull, UK, leveraging the company's previous experience in both biofuel production and animal feed production. The major innovations are described in more detail below.

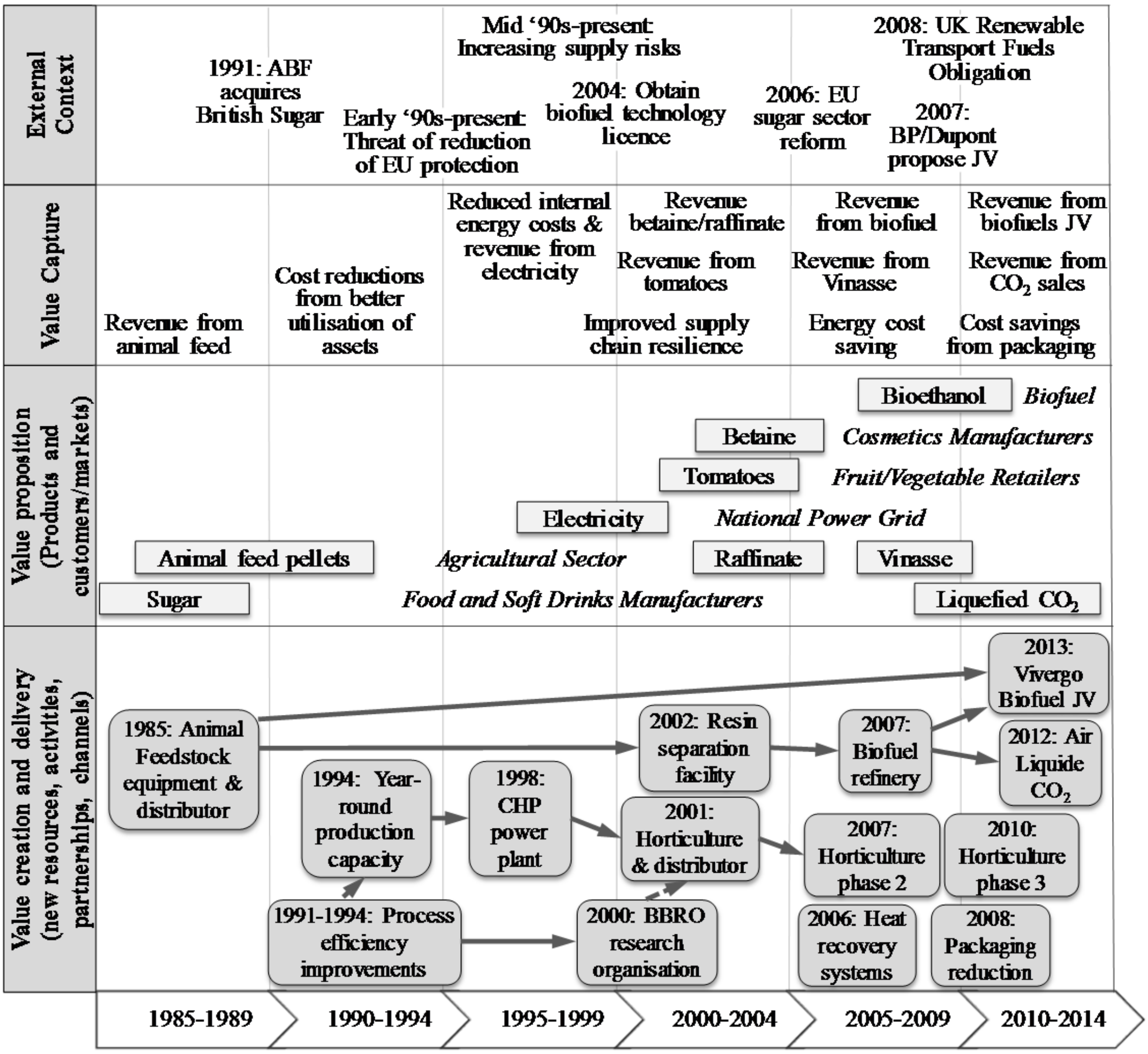

Figure 4. Evolution of the Wissington factory.

4.4 Innovations undertaken by British Sugar

This section explains the innovations in detail. Table 1 provides a summary in chronological order of the activities undertaken, the application of industrial ecology, and the implications for the business model at each step. The sub-sections provide a narrative account focussing on the most important *proactive* business model innovations (Schaltegger et al. 2012), including animal feed and co-product streams; establishing the British Beet Research Organisation (BBRO); tomato horticulture; resin separation facility to deliver additional co-products and bioethanol production.

Table 1. Business model innovations and industrial ecology at British Sugar, 1985-2013.

Activity	**Innovation**	**Industrial ecology principles**	**Business model implications** (Schaltegger et al. 2012)
1985: Animal feed	New facility installed for production of animal feed from waste bagasse (pressing and drying processes); subsidiary distribution company established to sell animal feed creating new revenue stream.	Utilization of waste bagasse. The waste stream was previously using in an anaerobic digester, or fed directly to livestock. This innovation allowed greater value capture – a form of internal symbiosis.	Proactive innovation – New value creation system, value proposition, and value capture mechanism. *(See section 4.4.1)*
1991-1994: Productivity improvements	New technology and equipment installed. Cost savings and higher utilization of production assets. Installation of storage silos allows crystallization part of factory to run year round.	Efficiency improvement, waste reduction, and maximising use of excess capacity.	Defensive innovation – Important process improvements, but not proactive business model innovation.
1998: Combined heat and Power (CHP)	New CHP installation – combined cycle gas turbine (CCGT) CHP generating steam for on-site use, and electricity. Lower energy costs on site and revenue stream associated with sale of electricity.	Higher productivity from energy content of fuel input, optimising efficiency of resources.	Accommodative innovation – Important process improvement, although incremental based on existing business model.
2000: British Beet Research Organisation (BBRO)	Research centre partnership established to assist growers in improving crop yields and profitability. Value is captured in improved crop reliability and security of supply.	Optimizing use of agricultural input materials such as nitrates, phosphates, pesticides, and maximizing yields.	Proactive innovation – seeking to change the value proposition and value capture for the growers as well as British Sugar. *(See section 4.4.2)*
2001: Tomato horticulture	New horticulture operation established. Comprehensive waste heat and flue-gas transfer system installed. New partnership established with distributor to access market.	Internal symbiosis utilising waste streams to support greenhouses. Natural ecology principles applied throughout greenhouses – organic growing, rain water recovery, in-situ composting.	Proactive innovation – new value creation activities, value proposition and value capture mechanism. (This was a new innovation for the sugar industry). *(See section 4.4.3)*
2002: Resin separation facility	New facility installed to process waste stream from sugar crystallization process. Produces betaine and raffinate that are sold as valuable co-products.	Internal symbiosis utilising waste flows from the core sugar product as feedstock for new process and products.	Proactive innovation – new value creation activities, value proposition and value capture mechanism. *(See section 4.4.4)*
2006: Heat recovery systems	New technology and equipment to recover heat from vapour discharged from the sugar evaporation process.	Efficiency and closing material/energy flows to reuse waste heat.	Defensive innovation – significant initiative to reduce costs and capture waste heat.

Activity	Innovation	Industrial ecology principles	Business model implications (Schaltegger et al. 2012)
2007: Biofuel refinery	New bio-refinery facility installed. Relationships with technology licensor/supplier for production technology and equipment, and fuel blender as distributor for the biofuel. New revenue stream and increased added-value.	Internal symbiosis – British Sugar uses waste stream from the resin separation system/ excess sugar production, as feedstock for their bio-refinery to create biofuel co-product. Provides flexibility to make use of excess sugar production.	Proactive innovation – new value creation and delivery activities, value proposition and value capture. Not new to the sugar industry (licenced from India), but innovation for the UK industry. *(See section 4.4.5)*
2008: Packaging reduction initiative	Initiative with suppliers to reduce packaging weight to save cost and reduce environmental impact.	Reduce paper usage/waste.	Defensive/Accommodative innovation – cost and waste reduction, reputational enhancement.
2012: Air Liquide CO_2	Partnership with Air Liquide to capture and sell liquefied CO_2.to various customers (e.g. soft drinks producers, fire protection manufacturers). Air Liquide built, owns and operates the liquefaction facility which is co-located at Wissington.	External symbiosis – a partner company participates in waste stream utilization creating value for both parties.	Proactive innovation – new value creation system, value proposition and value capture mechanism. *(See section 4.4.6)*
2013: Vivergo biofuels JV	New joint venture established to expand biofuels operation. Not co-located at Wissington, but building on technology and experience and utilising existing supplier relationships and distribution systems.	The new facility represents an example of internal symbiosis itself, combining a bio-refinery and an animal feed production facility, as the combined facility is wholly owned and operated by Vivergo.	Proactive innovation – new value creation system and new partners, new value proposition and value capture for British Sugar. *(Included in section 4.4.5)*

4.4.1 Animal feed and other Co-Product Streams

Internal symbiosis is not a term used within British Sugar, but this is a good descriptor of their approach, as several innovations have been introduced to create new products (co-products) from existing waste streams. When the raw sugar beet is delivered to the factory it includes soil and stones from the fields. Rather than discarding these, British Sugar captures value by separating, cleaning, sorting, and selling the stones to the building trade as aggregate, and selling the soil as high quality top soil for landscaping. Additionally, the sugar purification process precipitates calcium carbonate, which is reclaimed and sold as a soil conditioner, branded as LimeX for agricultural use. These initiatives date back to the early days of sugar production.

Sugar production also generates a by-product of bagasse (fibrous biomass) from the diffusion process. In 1985 British Sugar introduced a new facility to press and dry the bagasse into valuable high-fibre animal feed pellets. Prior to this the bagasse was not actually discarded – some was fed directly to animals and the balance was used in bio-digesters to generate methane for energy use. However, the new animal feed products represent a higher value-added use of the bagasse. Subsidiary companies were established by British Sugar for distribution of LimeX, TOPSOIL and Trident animal feed. Trident, established by British Sugar in 1984, initiated the development of an entire new division of Associated British Foods, now known as Associated British Agriculture, or AB Agri (See Figure 5 for organization chart). This division has become a major supplier of animal nutrition and feed products, distributing co-products from many other companies in the food and beverages production sector.

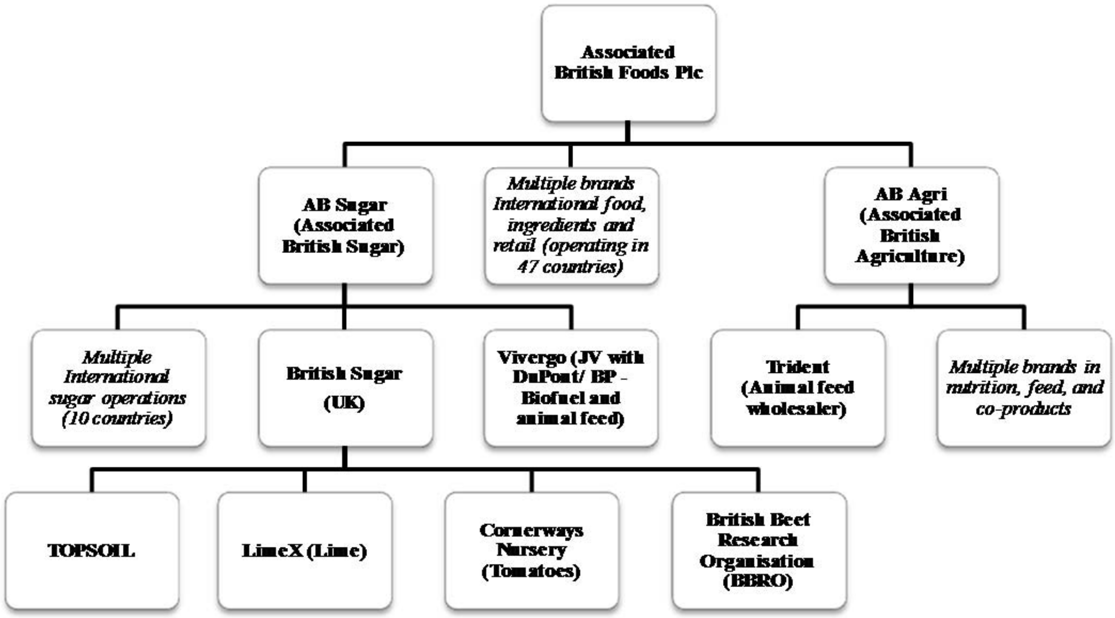

Figure 5. Organization chart showing parent companies and relevant subsidiaries.

4.4.2 British Beet Research Organisation (BBRO) delivering enhanced crop yields

Sugar beet has traditionally been viewed as a temperamental crop, and growers always have the option to shift to alternative potentially more lucrative or less risky crops. Therefore, working with the growers to improve crop yields has and continues to be an important element in ensuring competitive and reliable supply of the raw sugar beet. This is facilitated through close working relationships with the local agricultural community, and through direct investment in R&D. Through sampling of the raw sugar beet upon delivery to the factory, British Sugar is able to provide advice to growers to help optimize use of phosphates, nitrates, and pesticides, and minimize top soil degradation. Furthermore, in partnership with the National Farmers Union (NFU) they established a not-for-profit collaborative research initiative, British Beet Research Organization (BBRO), to commission and implement research and technology transfer to increase the competitiveness and profitability of the UK beet sugar industry. Over the past 30 years the growers, assisted by British Sugar, have achieved a 60% improvement in yield, and significant reductions in all the major chemical inputs to the growing process (British Sugar & NFU Sugar 2011). See Table 3 for details.

4.4.3 Tomato Horticulture

Among the more visible innovations at Wissington has been British Sugar's move into tomato growing and the co-location of 18 hectares of glasshouses alongside the sugar factory. Waste in the form of low-grade heat (hot water) from the sugar production process and CO_2 rich flue gases from the CHP boiler are transferred via pipes to the glasshouses, representing a form of internal symbiosis. The heated atmosphere of 4 times ambient levels of CO_2 enables tomatoes to grow at twice the usual rate providing high productivity for the glasshouse investment. The impetus for this initiative appears to have been at least in part a result of the company's employee suggestion scheme for seeking value from waste and a desire to utilize unused assets (the land surrounding the factory owned by British Sugar).

British Sugar is now the largest producer of speciality salad tomatoes in the UK, producing over 140 million per year, and is recognized as a class-leading organic horticultural operation. Further ecology-inspired innovations have been introduced to optimize the operations, including in-situ composting of plants to retain nutrients and eliminate potential waste to land-fill when the plants die at the end of the growing cycle. Furthermore, 115 million litres of rainwater are collected annually from the roofs of the glasshouses and recycled through the site minimising the need to draw on groundwater or other water resources. British Sugar retains full control of the horticultural operations; however, a partnership with a marketing consortium was established as an efficient channel to sell and distribute the fresh produce to local retailers.

4.4.4 Resin Separation – Additional Co-Product Streams

Extending the application of internal symbiosis, in 2002, British Sugar introduced a new facility to make use of the waste residual resin from the sugar crystallization process. Betaine, an organic compound which occurs naturally in sugar beet, is extracted from this process for sale to the healthcare sector for use in shampoos, moisturizers and cosmetics. Through this initiative British Sugar has become the largest supplier of natural betaine in the world. Additionally, raffinate is also extracted and sold as an animal feed supplement through Trident, the AB Agri subsidiary (See Figure 5).

4.4.5 Bioethanol production

In the mid-2000s identifying an emerging opportunity in the UK's renewable fuels road transport obligations, British Sugar launched a synergistic move into bio-fuels production based on fermentation of sugar products. British Sugar's bioethanol facility, co-located on the Wissington site, was the UK's first, and produces up to 70m litres of bioethanol per year for blending with gasoline for use as a renewable transportation fuel. This initiative followed already well-established practice in the sugarcane industry in India, and was developed through a relationship with the Indian licensor and equipment supplier, Praj Industries. The initiative makes use of waste sugar extracts from the resin separation process representing internal symbiosis, and also provides flexibility to utilize over-production of sugar products in years when sugar production exceeds quotas.

The business has been extended on a much larger scale with a new £300 million joint venture, Vivergo, between AB Sugar, BP and DuPont to produce bioethanol and animal feed from wheat. This initiative is not part of the Wissington factory, but has enabled AB Sugar and AB Agri to expand significantly. Vivergo opened in 2013 and has a production capacity of 420,000 litres of bioethanol and 500,000 tonnes of animal feed per year, making it the UK's largest provider of both. The project was initiated by BP, who, recognizing the established expertise in bioethanol and animal feed production, approached AB Sugar with the proposed joint venture. The new facility represents internal symbiosis between the product lines. Additionally, this could in part be described as a conventional dyadic symbiotic relationship, in which knowledge as well as material is shared between two companies (Chertow 2007).

4.4.6. CO_2 production through industrial symbiosis

The fermentation process involved in bioethanol production generates a very clean by-product of CO_2. Seeking to create value from this by-product, a partnership was established with a separate company with expertise in gas liquefaction to capture and liquefy the CO_2 for sale to the carbonated soft drinks sector and the fire protection industry. Air Liquide built, own and operate the liquefaction facility, but it is co-located on the Wissington site. The resulting business relationship is profitable for both companies, reduces local CO_2 emissions, and further evolves the business model from in-house to partnering externally for industrial symbiosis.

4.5 Contribution to competitive advantage

"We don't grow tomatoes just because it feels good to make effective use of our waste carbon-dioxide streams. We do it because we think we can make a return on the investment. It's a good example of how sustainability can be used to drive a business forward." Mark Carr, group chief executive of AB Sugar.

British Sugar's innovation strategy over the past three decades has delivered efficiency and productivity improvements and diversified revenue growth. During this period protection provided by EU agricultural policies has diminished, but nonetheless the company has not only survived, but has expanded. The core business of sugar is still subject to quota controls so sugar volumes are not greatly changed. Business innovations, however, help the company remain competitive in the sugar market, while the development of co-product lines and new ventures provides a diversified source of growth. Publically available industry data indicates British Sugar's contribution to AB Sugar's revenue for 2011-2012 was £1.05 billion, of which approximately £799 million was sugar related (75% of revenues) (IBISWorld 2013b). This suggests the remaining 25% of revenues is generated from co-products (the figure would be higher for Wissington because it has a broader range of co-products than the other British Sugar factories). Co-products as a percentage of total revenue show a positive growth trend over the past five-year period (IBISWorld 2013b), and are viewed as an important source for future growth (AB Foods Plc 2013b).

Competitive advantage can be determined either through a competitor-centred perspective or through a customer focus (Day & Wensley 1988). For confidentiality reasons, detailed financial performance data (e.g. investments, revenues, product line profitability) cannot be disclosed to assess the full extent of competitive advantage realized, or to determine the contribution of each co-product line. However, according to the interviewees each product line independently satisfied standard corporate investment criteria, is individually profitable, and has satisfied or exceeded planned return on investment. Although detailed financial data is not available, tonnage of production outputs, and in some cases market position, is publicly available as shown in Table 2. This illustrates the strength of the company in the various product categories, and provides a simple competitor-centric perspective on competitive advantage. For example, in the case of tomatoes, investment has been in three phases indicating the successful expansion of the business in a competitive market. Similarly, activities in biofuels have proven successful and have led to the significant extension through the Vivergo joint venture.

Table 2. Tonnage of all products produced at Wissington in 2012.
Supplemented with data from British Sugar (2012)

Category	**Product**	**Distributor/ Brand**	**Tonnes per Year (average)**	**Customer sector**	**Competitive position**
Sugar Product	Bulk granulated Bulk liquid Liquid blends Granulated bags	British Sugar (Retail brand Silver Spoon)	420,000 t	Food, drink and pharmaceutical manufacturers, and retailers	Largest producer in the UK with an 85.4% market share (IBISWorld 2013b). Also viewed as the most efficient beet sugar factory in Europe (IBISWorld 2013b)
"Co-Products"	Animal feed	Trident (Now a subsidiary of AB Agri, part of the AB Food group)	140,000 t	UK livestock farmers	Vivergo is UK's largest producer (500,000 t/yr.) (Company own data). Market concentration is low, but AB Agri is the largest player in UK market with 17.8% share in 2013 (IBISWorld 2013a) The company is viewed to lead animal feed production R&D (IBISWorld 2013a).
	Topsoil	TOPSOIL	50,000 t	UK landscape and gardening	UK's largest supplier of high quality top soil (Company own data).
	Soil conditioner	LimeX	120,000 t	UK agriculture, construction	UK's largest supplier of soil conditioner (Company own data).
	Stones/ Aggregate	British Sugar	500	Construction	
	Tomatoes	Cornerways Nursery	15,000 t (140m tomatoes)	Retailers	UK's largest grower – 20% of UK domestic production (British Tomato Growers Association 2013)

	Liquid Betaine	British Sugar	11,000 t	Healthcare and animal feed	Second largest global supplier of natural betaine (AB Foods Plc 2013b).
	Raffinate / Vinasse	Trident	76,000 t	Animal feed manufacturers	
	Bioethanol	British Sugar	Up to 55,000 t (70m litres)	Fuel blenders	First bioethanol facility in UK in 2007. The new Vivergo facility is UK's largest bioethanol producer representing about 30% of UK production (Spackman 2012).
	CO_2	Air Liquide	Up to 40,000 t	Soft drinks producers, fire protection sector	
	Electricity	British Sugar	320,000 MWh	Energy suppliers	

4.6 Ecological benefits realized

Table 3 provides a quantitative assessment of the major ecological benefits realized at the Wissington site based on publicly available data. Due to the company's highly integrated operations it is not possible to ascertain the precise contribution of each initiative to the overall benefits, but this should not detract from the overall results.

Table 3. Ecological benefits realized by Wissington.
Source: British Sugar & NFU Sugar (2011)

Measure	Scope	Ecological benefits realized over the three decades
Energy use	Energy used in transportation and production of sugar	• 25% reduction in energy per tonne of sugar, while simultaneously increasing range of co-products. • Beet is grown an average of 28 miles from the factory, minimising transportation requirements.
Water use	In growing sugar beet and within sugar production and tomato growing	• 95% of sugar beet is rain fed, so minimal irrigation. • Majority of water used in production processes comes directly from the sugar beet. • On-site effluent treatment of all water; factory is a net exporter of clean water. (Sedimentation lagoons attract bird life so also enhance biodiversity)
CO_2 emissions reduction	CO_2 reduced through tomato growing operations, capture and liquefaction operations, and supply of biofuels	• Biofuels represent a 70% CO_2 emissions saving on a full life-cycle basis. • Tomatoes grown in atmosphere of 4 times CO_2 content of normal air, growing at twice normal rate.
Waste to land-fill	Reuse of waste (by-products) from core production line became valuable end products or feedstock for another production process	• Since 2003 waste to landfill has been reduced by 50%. In 2010 2,200 tonnes of scrap wood, plastic, metal, paper and solvents were recycled; in 2012 only 256 tonnes went to landfill.

Reduced packaging materials	Packaging materials used in shipping final products	• Majority of products delivered in bulk eliminating need for any packaging. • For the remainder, an initiative to reduce packaging in 2009 saves 40 tonnes of paper per year.
Agricultural land use	Sugar beet crop productivity	• Productivity increase of 60% yield over the past 30 years (now 11 tonnes of sugar per hectare), has enabled a 48% reduction in land use for growing. • Soil removed during beet harvest is recycled as high quality topsoil.
Agrochemical use	Agricultural chemicals used in sugar beet growing	• Since 1980 nitrogen usage reduced by 40% (lowest of any arable crop), pesticides reduced by 60%, phosphates reduced by 70%.

5 Discussion

5.1 The pathway towards sustainability

British Sugar's evolutionary path reflects Davidson's (1999) three phases of business transformation, discussed in section 2.4. Figure 6 shows the company's initial focus on productivity and efficiency (e.g., 1990s consolidation of factories, capacity expansion, efficiency enhancements), which promoted a cultural shift towards seeking value from waste streams, and a 'waste nothing' mind-set that is now evident from the shop floor to the executive level (e.g., early 2000s development of 'co-product' business lines such as tomatoes). Over time, this has evolved, enabling the company to realize long-term competitive advantage through diversification (e.g., late 2000s entry into bioethanol production, and the Vivergo joint venture between AB Sugar, BP, and DuPont). Comparison with similar initiatives such as Guitang Group in China suggests a comparable transition path for the successful introduction and development of industrial ecology and embedding sustainability in the business.

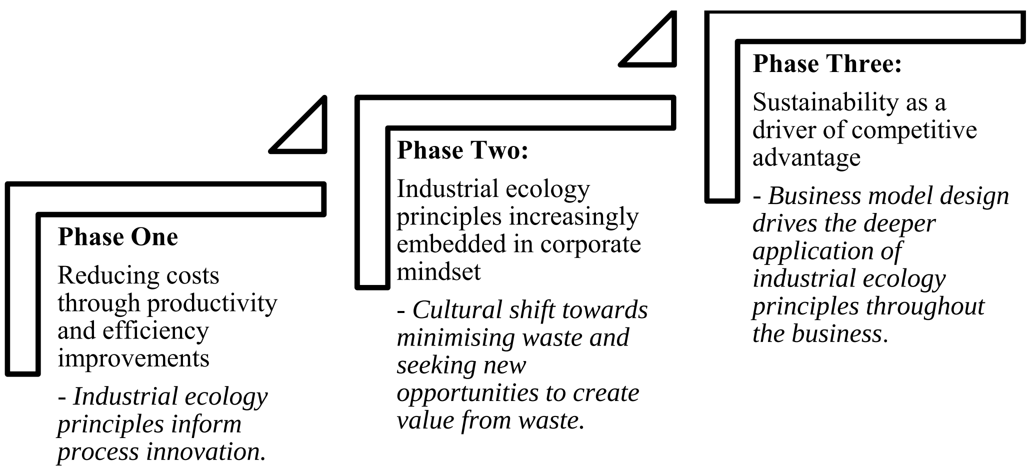

Figure 6. British Sugar's transition path towards sustainability, based on Davidson (1999)

The case suggests the process of business model evolution involves important learning activities in which the firm develops new skills and abilities, the mind-set of innovation and adaptation, and an appetite for searching out new value creation opportunities.

Stepping beyond the boundaries of the existing firm/industry is challenging, but having achieved initial success it appears that the management, organizational and cognitive barriers (Christensen 1997) are reduced, making future experimentation and success more likely. Moreover, the skills developed may open up increasingly broader opportunities beyond the core business.

In the work that has been presented, it is easy to see why a single firm may want to act on its own, avoiding entanglements with other firms that may reduce its autonomy and create interdependencies. Among multiple firms each company in a symbiotic network may be inclined to take a narrow perspective on the immediate costs and benefits of the waste streams exchanged (Ehrenfeld & Gertler 1997), and focus on optimising its own core business rather than adopting a more strategic perspective on network development (Esty & Porter 1998). Yet, some industrial symbiosis networks have been seen to be resilient over time, able to shed old exchanges and continue to develop new ones across multiple firms (Ehrenfeld & Chertow 2002; Chertow & Miyata 2011). Indeed, in the case of British Sugar and similar cases such as the Guitang Group (Zhu et al. 2007), we see that internal symbiosis eventually evolved into industrial symbiosis as additional firms outside of the sugar companies provided new growth opportunities and potential risk reduction.

The case study illustrates how an industrial ecology-based strategy can facilitate the development of knowhow and market access that subsequently enables entry into larger-scale opportunities unrelated to the original core business line. British Sugar's journey appears to have evolved in a somewhat ad-hoc manner. However, development with a view of the longer term progression is desirable – some activities have to happen in a certain sequence or cannot evolve at all; in other cases, partial steps may be possible to reduce the risk exposure and upfront capital costs. Conversely, the case also illustrates the need to respond dynamically to emerging market opportunities and threats, and that design for flexibility is advantageous to ensure long-term business sustainability – for example, the bioethanol facility provides British Sugar not only with a use of a waste stream, but also an alternative use for sugar as the sugar market changes.

5.2 Factors enabling industrial ecology and business model evolution

The innovation process at British Sugar is built upon the core business of sugar production. Importantly, this provides a stable platform around which the business has been able to expand into new areas. A robust selection process demanding economic benefits to be realized from all innovations is a key feature of the management decision making process, specifically enquiring what additional value each new innovation captures for the company. Incremental innovation steps have allowed the company to gain experience and confidence from each new initiative, and gradually expand the scope further from the core business. Three important organizational factors are identified in British Sugar's management practices:

1. Dedicated innovation teams are established to develop each new product line to ensure management focus. At the strategic level the company has developed a structured approach to innovation, creating a development road map for identifying potential related product opportunities to take the company further beyond the current product lines.

2. Communication between product line managers is important to identify new opportunities, and ensure the smooth integration and cooperation between co-product lines. To avoid creating business silos, as a general rule the co-product lines are integrated into the existing business and management practices, rather than creating independent business units. Exceptions are made when justifiable, for example, introducing tomato horticulture specialists due to the very different nature of the business line.

3. Collaboration with suppliers and partners has been a hallmark of many of the initiatives, from working with farmers to improve yields, collaborating with GE to optimize operation of CHP gas turbine, and Praj Industries for bio-refinery technology. Careful consideration of when to partner, when to bring in expertise, and when to outsource, has underpinned the development of new business lines.

5.3 Industrial ecology and business model evolution

The British Sugar case illustrates that industrial ecology principles can be embedded in every step of business model evolution. Symbiotic exchanges, whether internal or external, are perhaps most potent for business model innovation when they go to the core of the business model – introducing change in all three of its dimensions – value proposition (new co-products and new customers), value creation system (new resources and activities – technology, production processes, relationships), and new sources of value capture for the firm (new revenue streams). More important, it suggests that reconceiving industrial ecology and industrial symbiosis from a business model perspective may extend its application and enhance sustainability outcomes. That is, by actively seeking out business model innovation opportunities (new opportunities for value creation) it may be possible to broaden the uptake of industrial ecology principles and accelerate sustainability initiatives by bringing a stronger business development focus to bear.

6 Conclusion

The British Sugar case illustrates how industrial ecology principles, and particularly industrial symbiosis, can be closely aligned with business model innovation for sustainability. The link between these two literature fields is growing, and the case demonstrates the potential benefits in bringing the fields closer together. Both offer a system-perspective on innovation and seek to deliver environmental and economic benefits. However, whereas industrial ecology generally focuses on environmental benefits, the business model perspective helps place greater emphasis on new value creation. Although both literature themes overlap, they also complement each other.

The presented case reveals how British Sugar enhanced the competitiveness of its core sugar business, while successfully expanding into new and diversified markets, increasing revenue streams, and enhancing business resilience. Their strategy has also delivered significant environmental benefits through improvements in energy efficiency, successful capture and reuse of by-products, reduction of land-fill waste and waste water, and improved use of agricultural land. The case demonstrates how focusing on turning all by-products into valuable co-products can create competitive advantage and help to ensure the long-term future of a company by presenting new business opportunities.

Several aspects of the business evolution at British Sugar are described as a single-firm implementation of industrial symbiosis (under single ownership). With the benefit of hindsight, we see in the case of British Sugar that these can, over time, be seen precursors to multiple industry symbiotic development. This occurred in a similar way to the examples referenced of Guitang in China and Seshasayee Paper and Boards Ltd in India. As such, industrial ecology principles can offer a strategic approach to business development, leading in some cases to new business opportunities that might otherwise have been inaccessible (e.g. the Vivergo development for British Sugar). This seems a significant form of competitive advantage suggesting that diversified business models linked through internal resource exchanges could be an important feature for development of future sustainable industrial systems.

Conclusions of this article are based on one single in-depth case study, which, while providing a good basis for theory building and generalizability, is also a limitation. Therefore, additional study of a broader set of cases would be beneficial. Future research is also recommended to investigate how companies might adapt their business model innovation and planning processes to recognize and explore opportunities for integrating industrial ecology principles and developing symbiotic value creation to transform by-product streams into profitable core business activities more readily. Ultimately, this may help to make industrial symbiosis a more common approach to delivering environmental sustainability and competitive advantage through business model innovation.

7 Acknowledgements

The authors gratefully acknowledge the extensive access to information and in-depth interviews made possible by British Sugar and AB Sugar in support of this case study. This article builds on initial work undertaken on SustainValue, a European Commission's 7th Framework Programme (FP7/2007-2013). The authors gratefully acknowledge the funding support of the European Commission, and the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability.

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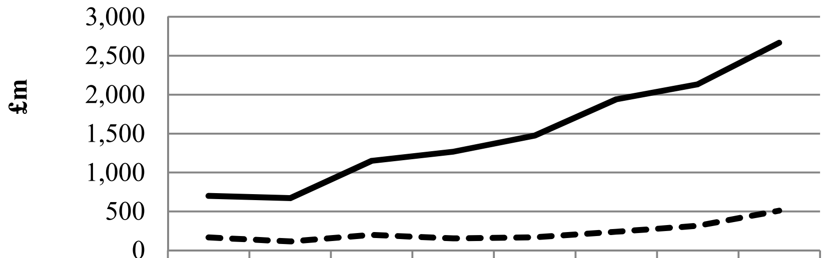
Supplementary Data



	2005	2006	2007	2008	2009	2010	2011	2012
Revenue (£m)	700	671	1,151	1,267	1,475	1,941	2,134	2,666
Operating Profit (£m)	166	115	199	153	168	240	315	510
Profit %	23.7%	17.1%	17.3%	12.1%	11.4%	12.4%	14.8%	19.1%
ROI %					11.8%	14.0%	17.0%	26.0%

Financial Year Ending

Figure 1. Financial Performance of AB Sugar Group (AB Foods Plc 2013a)

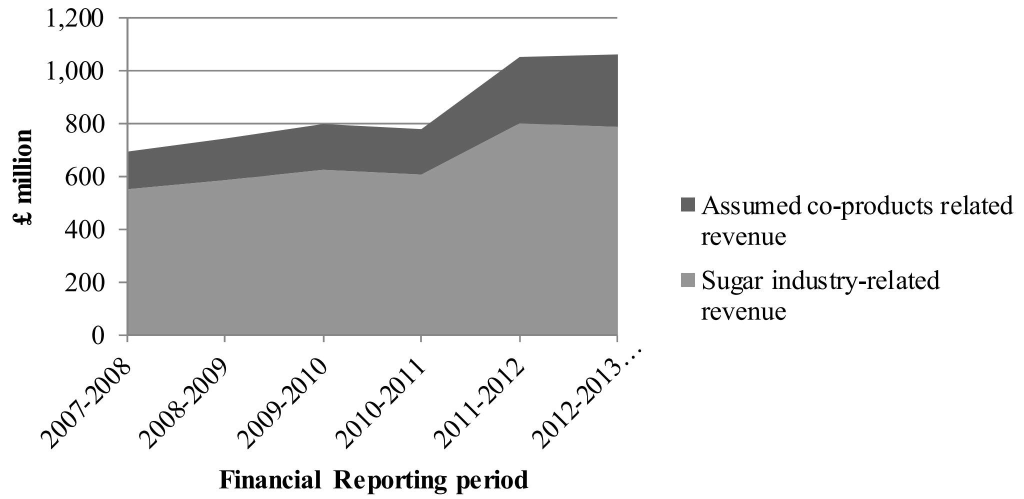


Figure 2. Revenue of British Sugar – Sugar business and co-products (IBISWorld 2013b).