

1.0 Introduction

The rum industry is a significant industrial sector in Puerto Rico in terms of value to the economy and cultural heritage. There are two major companies that presently manufacture rum on the island: Destilería Serrallés and the Bacardi Corporation, located in Ponce and Cataño respectively. Although producing similar products, the two companies differ markedly in terms of business model, market, production process, size and scale of operations. Despite these differences, industrial symbiosis can potentially benefit both companies, providing economic as well as environmental value.

1.1 Industrial Symbiosis

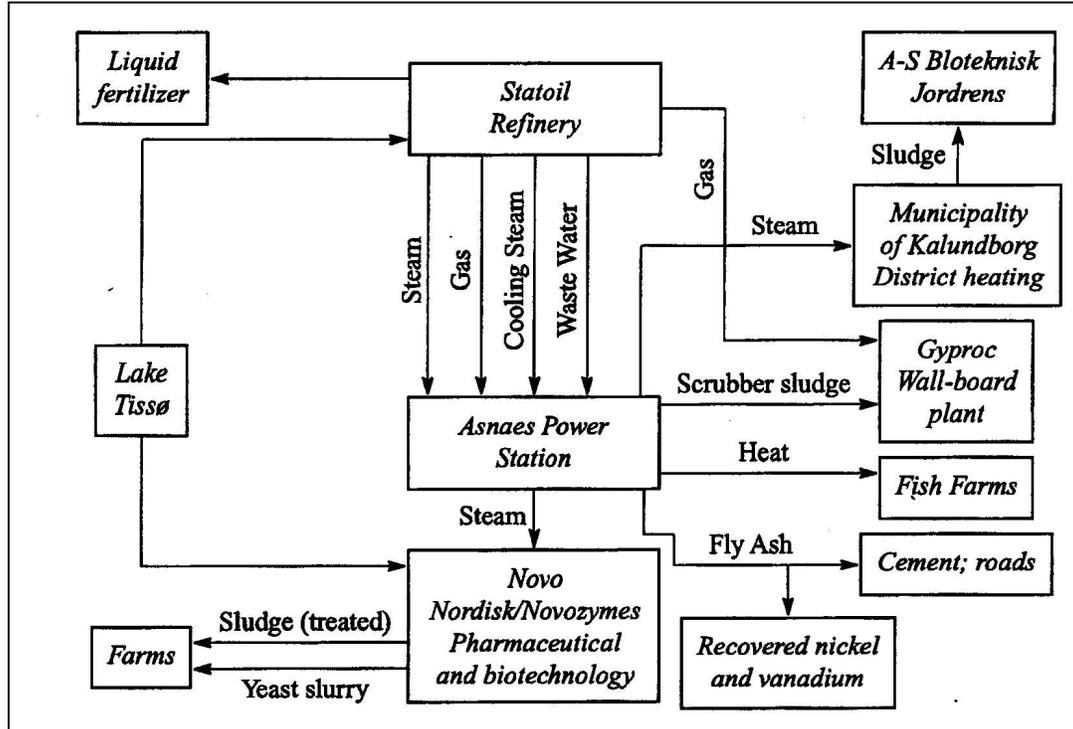
Industrial symbiosis draws on key concepts from the field of industrial ecology, such as tracking the flow of materials, loop closing, and the cascading of energy, water and materials. Chertow (2000) defines industrial symbiosis as,

...engag[ing] traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or byproducts. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.

There are five types of industrial symbiosis relationships that can be employed to share items such as material inputs and outputs, information, regulatory functions, transportations systems, and marketing. Type I relationships are waste exchanges, such as scrap yards and web-based material exchanges. These interactions are unplanned. Type II relationships are intra-firm, facility or organization relationships. These types of relationships try to optimize production by utilizing the byproduct of one process as the feedstock for another. Type III relationships are among firms co-located in defined industrial areas or eco-industrial parks. These types of relationships take advantage of co-location to organize the sharing of inputs and the exchanges of byproducts. Type IV relationships are among nearby or local firms not co-located. The material exchanges evidenced among firms in Kalundborg, Denmark, discussed below, are a prime example. Type V industrial symbiosis relationships are among firms organized across regions. (Chertow, 2002)

The case of Kalundborg, Demark, a small coastal industrial city 75 miles west of Copenhagen, is an example of an effective Type 4 industrial symbiotic relationship providing added value to the economic and environmental profiles of the companies involved. The six core partners engaged in the waste exchanges in Kalundborg are the Asnaes Power Station, the Statoil refinery, the pharmaceutical firm Nordisk Novozymes A/S, plasterboard manufacturer Gyproc Nordic East, soil remediation firm A-S Bioteknisk Jordrens, and the city of Kalundborg (Figure 1).

Figure 1. Conceptual model of materials exchanges in Kalundborg, Denmark



Source: Chertow (2002)

This report intends to apply the Kalundborg example as a model for the rum industry in Puerto Rico to identify opportunities for material exchanges that can contribute to the economic and environmental benefit of each firm individually and to the island as a whole.

1.2 The Rum Industry in Puerto Rico

The rum industry has a long history in the Caribbean. In 1493, Christopher Columbus brought sugar cane to the present-day countries of Haiti and the Dominican Republic. With the introduction of sugar cane, the primary ingredient in rum-making, rum production started on almost all of the 700 Caribbean islands (Fried, 1991). During the era of European colonization, the sugar industry meant that the “Caribbean colonies [were] of central importance for economic development” and they “became a focal point of international political conflict as the colonizing powers vied with one another” (Mandala 2000, p.1).

The rum industry continued to thrive across the Caribbean for many centuries, but it was not until the 1960s that world demand for rum increased sharply. During this period, there were a number of firms competing in the market. By the end of the decade, only a few large distilleries survived. Rum sales increased throughout the 1970s (Mandala, 2000). In recent years, rum has seen another growth in sales. *Advertising Age* reports:

Rum was the country's fourth-most-popular spirit last year, following vodka, Canadian whiskey and cordials, according to the most recent figures from industry publication *Impact*. Category sales have been on the upswing since 1994, when they bottomed out at 11 million cases; this year, they could exceed 16 million, according to *Impact* (Chura, 2001, p.2).

Economic success in the rum industry in Puerto Rico is particularly important in recent years, as the island has experienced a decline in annual economic growth, falling from 3.7% from 1997-2001 to 1.7% in 2001 (EIU, 2002).

1.2.1 History of Bacardi

Bacardi is a multinational corporation, founded initially in Cuba in 1862 (Moskowitz & Levering, 2003). The Bacardi Corporation has experienced several periods of rapid growth. The firm dominated the United States spirits market in the mid-1970s and the world spirits market shortly thereafter. In the 1990s, Bacardi continued to grow. The introduction of new products and acquisition of beverage companies, such as Martini Vermouth and Bombay Sapphire gin, further propelled Bacardi's growth. Today the company employs 6,000 employees and sells 60 million cases of spirits per year in 170 countries (TME, 2002; Bacardi, 2003). The main Bacardi distillery site is located in Cataño, Puerto Rico and was founded in 1944 (EPA, 1979). The plant in Cataño had revenues of \$398 million in 2002 (S&P, 2003).

1.2.2 History of Serrallés

Destilería Serrallés was founded in 1865 on the Hacienda Mercedita sugar plantation near the city of Ponce, Puerto Rico (Ayala, 2001; Serrallés, 1999). The company grew significantly when it bought Puerto Rico Distillers in 1985. This acquisition increased the company's product line to include Palo Viejo, Ron Llave and Granado and doubled the firm's sales. Destilería Serrallés also has the rights to produce the Captain Morgan brand for distribution by Diageo in the U.S. market and to distribute this brand and others in Puerto Rico (Ayala, 2001; Serrallés, 2003). Today Serrallés has revenues of \$114.24 million (Lopez, 2002) and produces 80 varieties of rum products, such as DonQ, Bay Rum, and Captain Morgan Rum (Serrallés, 1999). The distillery manufactures 60% of the rum that is consumed in Puerto Rico (Ayala, 2001).

1.3 Environmental Issues Associated With Rum Production

Thus far, most research on improving the environmental performance of the rum industry has centered on mosto, a nutrient-rich byproduct of the fermentation and distillation processes. The U.S. Environmental Protection Agency ("EPA") conducted a detailed analysis of the detrimental effects of mosto discharge into the ocean in its 1979 report, "Caribbean Rum Study: Effects of Distillery Wastes on the Marine Environment." The report found that the mosto reduced marine dissolved oxygen, impacting the survival of marine life. Furthermore, it stated that the mosto contained toxic substances, as defined by the 1977 Clean Water Act (EPA, 1979).

Other areas of environmental concern involve solid, gaseous and aqueous residues; energy use, packaging, and recycling. Solid, gaseous and aqueous residues are created across many stages of the product life cycle. Much energy is used for plant operation and for transport of inputs, often from overseas. Finally, the feasibility of product recycling is very important and must be included in any detailed analysis of the environmental performance of the industry. These issues are discussed in Section 4 and evaluated in Section 5 of this report.

1.4 Environmental Regulation of Rum Industry

There are two main levels of environmental regulation in Puerto Rico associated with the rum industry, Federal and Commonwealth.

EPA is the lead regulatory agency for environmental issues at the Federal level, primarily concerned with regulating emissions from the facilities. There are three main Federal laws that govern the environmental management practices related to the emission of solid, gaseous and aqueous residues, namely the Resource Conservation Recovery Act (“RCRA”), Clean Air Act and Clean Water Act. Regarding the rum production process, as outlined in Section 3, RCRA regulates the transportation, storage and disposal of hazardous materials that are used or generated in the manufacturing, such as No. 6 oil; the Clean Air Act regulates the emissions of criteria air pollutants, including nitrogen oxides, sulfur dioxide, and particulate matter, from stationary sources such as boilers; and the Clean Water Act regulates and sets standards for the discharge of wastewater effluent to water bodies, which includes the mosto.

At the Commonwealth level, the environmental aspects of rum production are primarily regulated by three government agencies, the Junta de Calidad Ambiental (“Environmental Quality Board” or “EQB”), the Departamento de Recursos Naturales y Ambientales (“Department of Environmental and Natural Resources” or “DNER”) and the Autoridad de Acueductos y Acantarillados (“Puerto Rico Aqueduct and Sewer Authority” or “PRASA”). The EQB is the lead agency in Puerto Rico responsible for the environmental regulation and compliance. The EQB is responsible for implementing and monitoring compliance of delegated Federal environmental programs and Commonwealth environmental laws. DNER is the principle agency responsible for the protection and management of Puerto Rico’s natural resources, including the permitting and monitoring of water resources. PRASA is responsible for the treatment and distribution of drinking water and wastewater on the island.

2.0 Research Approach/ Methods

This study employed the use of literature reviews, field interviews, site visits, Life Cycle Analysis (“LCA”) and Streamlined Life Cycle Analysis (“SLCA”) methodology.

Prior to the field work, a review of both industrial symbiosis and the rum industry was conducted to understand the production process and identify potential aspects of the production processing where industrial symbiosis could be utilized.

The field work occurred in Puerto Rico during the week of March 17th, 2003. During the week, the research team interviewed experts from the Universidad de Puerto Rico - Recinto Universitario de Mayaguez, the Puerto Rico Environmental Quality Board, Destilería Serrallés and the Bacardi Corporation. A schedule of the meetings appears below (Table 1).

Table 1. Schedule of Meetings in Puerto Rico

Date	Tuesday March 18, 2003	Wednesday March 19, 2003	Thursday March 20, 2003	Friday March 21, 2003
Location	University of Puerto Rico, Mayaguez	Serrallés, Ponce	Bacardi, Cataño	Environmental Quality Board (EQB), San Juan
Morning Appointments	Meeting with Prof. Jose Collucci, professor of chemical engineering	Meeting with Roberto Serrallés and Henry Huertas, Compliance Director	Meeting with Dr. Szendrey, vice president of Bacardi Corporation	Meeting with Environmental Quality Board
Afternoon Appointments	Meeting with Prof. Collucci’s students to discuss Serrallés project Meeting with Prof. Sonia Borges, professor of biology to discuss vermi-composting for the Serrallés facility	Tour of facilities at Serrallés distillery	Tour of facilities at Bacardi distillery	

The data collected during the site visits and interviews was used as by the research team to map the flow of materials in the production process. Accounting for these material flows, the research team then studied how the environmental performance of the rum industry could be improved. The LCA and SLCA were used as the methodology for this evaluation and the selected method was chosen for each facility based on the availability of data. The results of the LCA, performed for Destilería Serrallés, and the SLCA, performed for the Bacardi Corporation were used to evaluate the potential industrial symbiosis relationships for the production inputs and non-product outputs.

3.0 Process

Since the first rum was produced in the Caribbean some 400 years ago, the production process has changed little. Although technological innovations have changed the details of how rum is made, the basic process is still the same. Rum is usually made from molasses, the byproduct of sugar production. The molasses is fermented to turn the sugar into alcohol, then the rum is distilled to remove impurities and most of the water, and finally it is aged, to give it the taste and aroma of rum. The process varies depending on the part of the world where the rum is being made, and between companies too, which results in a variety of different rums. In Puerto Rico, both the Bacardi Corporation and Destilería Serrallés, use the similar basic process, however, a few differences exist both in the actual rum production, as well as the way they deal with the treatment of waste, or other inputs and outputs of the rum making process.

3.1 Fermentation

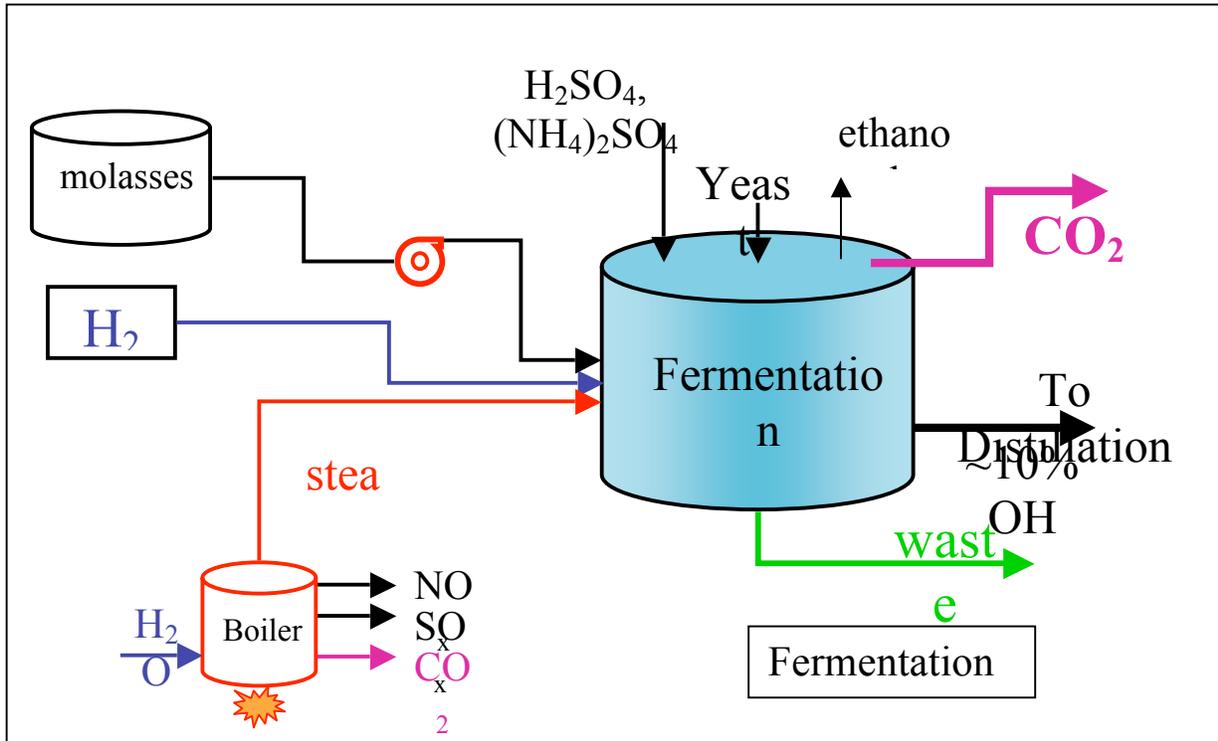
The first step in making rum is to get the alcohol (ethanol) through fermentation. During this process, the sugars in the molasses are mixed with yeast, which serves as a catalyst, to create ethanol. Although the specifics of the reactions between the yeast and the molasses are complex, the overall result is as follows:



Since the amount of sugar in the molasses determines the amount of alcohol that gets produced, rum manufacturers are constantly looking for the molasses which are highest in sugar concentration. However, this means that the sugar production (from where the molasses come as a byproduct) must be more inefficient. Therefore, the byproduct of bad sugar manufacturers becomes a highly demanded product for the rum industry. Other chemicals are also involved in the fermentation process, such as acids for pH control, and ammonia sulfate and phosphate, which provide nitrogen and phosphorus for optimizing the efficiency of the process. A lot of liquid water is also added to dilute the molasses and steam is used to provide energy, decrease the viscosity and help to mix everything more thoroughly.

The fermentation takes somewhere between 40 and 50 hours depending on the manufacturer and the yeast used, and because it is an exothermic reaction, cooling is important to keep the yeast at the optimal temperature for the most efficient conversion of the sugar to alcohol. Heat exchangers and cooling towers are used to get rid of the excess heat. At the same time, the carbon dioxide which is produced is being collected and sold to carbonated beverage manufactures in Puerto Rico.

Figure 2. The Rum Production Process: Fermentation



At the end of the process, the mixture is about 10-12% alcohol by volume (which is limited by the yeast) and this liquid is carried to the next stage, which is the distillation. The yeast, which is mostly protein, has increased during that time by about 13 times, and it remains in the tank, which is then cleaned with warm water. This is the waste of the fermentation process, which is very high in concentration of organic solids.

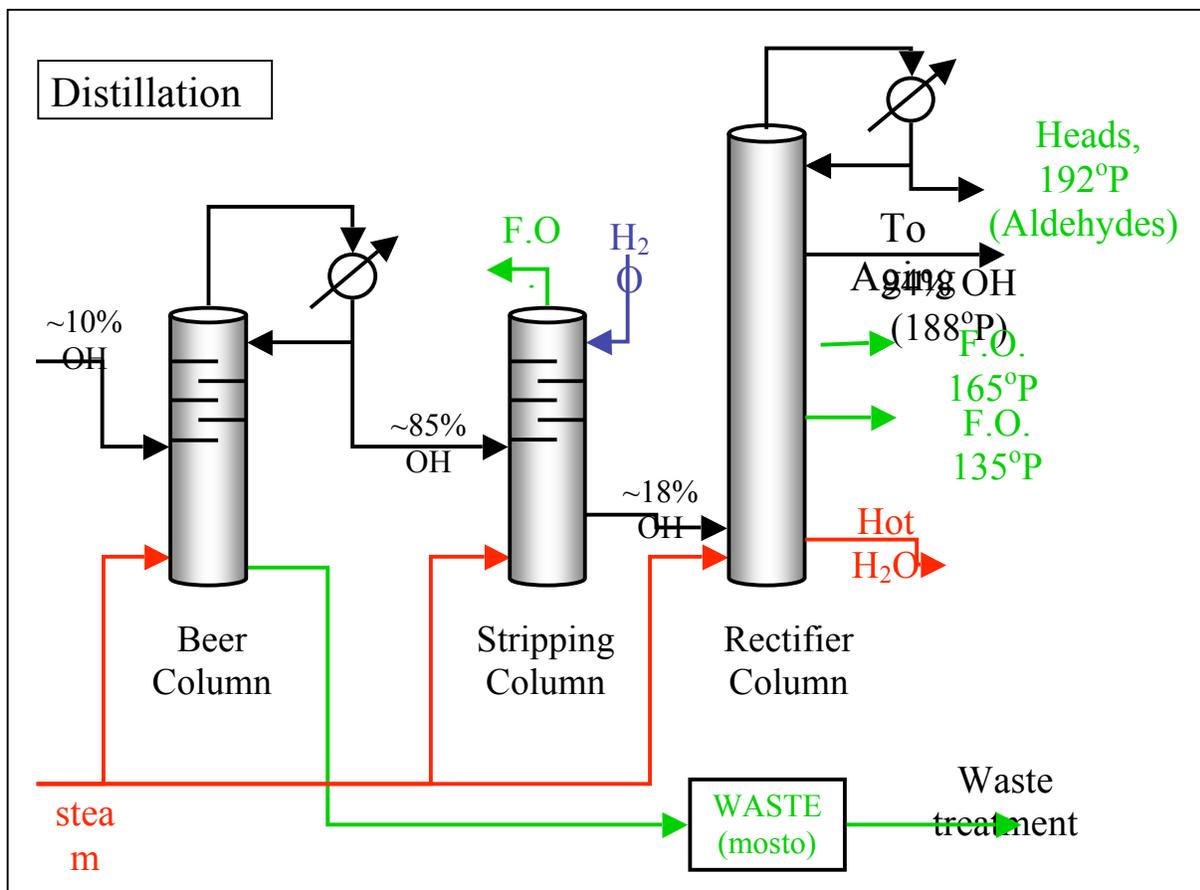
3.2 Distillation

The distillation process is very important for two basic reasons. Firstly, it removes most of the water which we added during fermentation, giving a product high in alcohol, and secondly, it removes the impurities and other harmful substances, such as methanol, which can be poisonous for humans. There are two methods of distillation, pot still distillation, and column distillation. The latter is used in Puerto Rico, and in fact there are some differences even between the two manufacturers, with Bacardi Corporation using a 4 column system, and Destilería Serrallés using 3 distillation columns.

Although the details may differ, the basic idea of distillation is to use high columns, provide energy from the bottom to evaporate the inputs, and exploit the difference in their boiling temperatures in order to separate the different substances. Ethanol has a boiling temperature of 78.3°C and water boils at 100°C, which means that ethanol evaporates first, and escapes from the top of the column, while water is recovered from

the bottom, and together with the other impurities, is called 'mosto', the waste of the distillation process. The other columns are used to remove impurities which come out as heads or tails, but in the end the rum has to be distilled, by law, to at least 180 proof, which means 90% alcohol, although it is usually distilled at about 94%. It is interesting to note that because of hydrogen bonding between ethanol and water molecules, the mixture of 95.6% ethanol and 4.4% water is azeotropic, which means that it acts as a pure substance with boiling temperature of 78.15°C, lower than that of pure ethanol. For that reason, it is physically impossible to get more than 95.6% ethanol through distillation alone, and other modern techniques are used to produce pure ethanol for other applications.

Figure 3. The Rum Production Process: Distillation



The above figure (Figure 3), based on the process used by Destilería Serrallés, shows how each column has a different function. The beer column removes the bulk of the water, along with the heavier wastes, the stripping column is used to remove the lighter waste that come out as heads, and the larger rectifier column gives the final product by removing the remaining impurities that come out below the product, and the aldehydes that come out as heads. Note that there are different energy transfers going on, some

by using steam to heat the columns, and heat exchangers are used to remove heat and condense the heads before they are recovered.

3.3 Aging

The last important stage of making the rum is aging. Puerto Rican law requires rum to be aged on the island for a minimum of 1 year, although some more selective rums are aged for longer. Oak barrels from the whiskey industry are used, usually charred, and the complex chemical reactions during the aging process give rum its characteristic taste. However, during aging, a significant amount of ethanol is lost through evaporation, which can be of the order of approximately 10% of the initial quantity. This portion, often referred to as the 'angel share', is a significant loss for the manufacturers, and although changing the humidity and temperature conditions might help minimize these losses, it is still uncertain how that might affect the quality of the rum.

3.4 Blending and Bottling

After the rum is properly aged, it is usually blended with rums from different barrels or different aging time, to maintain consistent quality and taste regardless of seasonal discrepancies that may result in the manufacturing process, the weather, or other variables. The rum is then bottled and shipped to the distributors.

4.0 Material Flows

The following figures (Figures 4, 5, 6, 7) demonstrate the flows of materials conceptually and geographically from source, through inputs, to product and non-product outputs.