THE INDUSTRIAL SYMBIOSIS IN KALUNDBORG, DENMARK.

1. INTRODUCTION.

It is important to point out that the example of Kalundborg in Denmark strictly speaking is an example of an *industrial network*, and not an industrial estate. However, as a case study it is an excellent illustration of the application of an Industrial Ecology approach and is certainly relevant to an industrial estate. The example of Kalundborg is often quoted in the literature, perhaps because it is simple enough to allow the idea of an industrial ecosystem to be appreciated and yet sufficiently sophisticated to give a feeling for the enormous potential of this approach.

2. BACKGROUND.

The history of Kalundborg really began in 1961 with a project to use surface water from Lake Tissø for a new oil refinery in order to save the limited supplies of ground water (Christensen, 1999). The city of Kalundborg took the responsibility for building the pipeline while the refinery financed it. Starting from this initial collaboration, a number of other collaborative projects were subsequently introduced and the number of partners gradually increased. By the end of the 1980's, the partners realised that they had effectively "self-organised" into what is probably the best-known example of a working industrial ecosystem, or to use their term - an *industrial symbiosis*.

3. PARTICIPANTS IN THE INDUSTRIAL SYMBIOSIS.

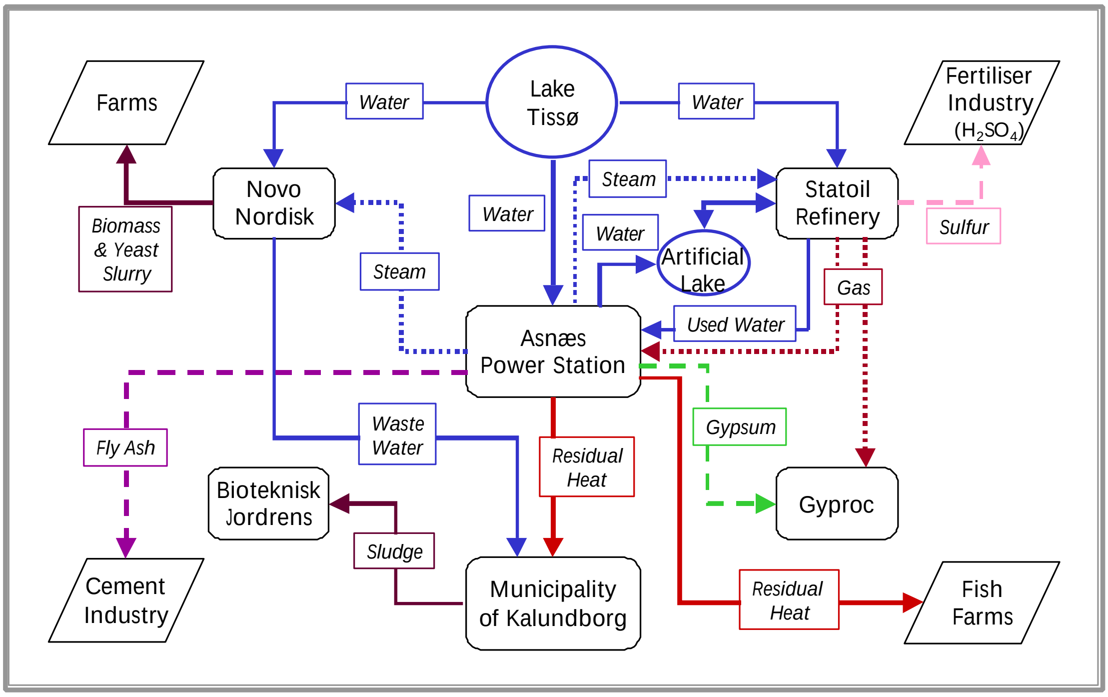
In addition to several companies that participate as recipients of materials or energy, the ecosystem today consists of six main partners -

- Asnæs power station - part of SK Power Company and the largest coal-fired plant producing electricity in Denmark.
- Statoil - an oil refinery belonging to the Norwegian State oil company.

- Novo Nordisk - a multi-national biotechnology company that is the largest producer of insulin and industrial enzymes.
- Gyproc - a Swedish company producing plasterboard for the building industry.
- The town of Kalundborg, which receives excess heat from Asnaes for its residential district heating system.
- Bioteknisk Jordrens - a soil remediation company that joined the Symbiosis in 1998.

The status of the industrial symbiosis in 1999 is shown in Figure 1 (Christensen, 1999). From this diagram we can appreciate how extensive the collaboration regarding materials and energy is. In our discussion here, however, we shall focus only on the most important flows.

<u>**Figure 1**</u>**:** Material Flows in the Kalundborg Industrial Ecosystem [Christensen, 1999].



4. MATERIAL & ENERGY FLOWS – A SERIES OF BY-PRODUCT SYNERGY PROJECTS.

It is important to understand initially that ***water*** is a scarce resource in this part of Denmark and is therefore systematically valorised. As we mentioned above, in order to reduce consumption of ground water, Lake Tissø has become the main source of water for the industrial partners in Kalundborg. The reduction in the use of ground water has been estimated at close to 2 million cubic metres per year (Christensen, 1999). However, in order to reduce overall water consumption by the partners, the Statoil refinery supplies its purified wastewater as well as its used cooling water to Asnæs power station, thereby allowing this water to be "used twice" and saving additionally 1 million cubic metres of water per year.

Asnæs power station supplies ***steam*** both to Statoil and Novo Nordisk for heating of their processes. By functioning in a co-generation mode, the power station is able to increase its efficiency.

Excess gas from the operations at the Statoil refinery is treated to remove ***sulfur***, which is sold as a raw material for the manufacture of sulfuric acid, and the clean ***gas*** is then supplied to Asnæs power station and to Gyproc as an energy source.

In 1993 Asnæs power station installed a desulfurisation unit to remove sulfur from its flue gases, which allows it to produce ***calcium sulfate*** (gypsum). This is the main raw material in the manufacture of plasterboard at Gyproc. By purchasing synthetic "waste" gypsum from Asnæs power station, Gyproc has been able to replace the natural gypsum that it used to buy from Spain. In 1998 approximately 190,000 tons per year of synthetic gypsum were available from the power station.

Novo Nordisk creates a large quantity of used bio-mass coming from its synthetic processes and the company has realised that this can be used as a fertiliser since it contains nitrogen, phosphorus and potassium. The local farming communities use more than 800,000 cubic metres of this liquid ***fertiliser*** each year as well as over 60,000 tons of a solid form of the fertiliser.

Finally, residual ***heat*** is also provided by Asnæs power station to the district heating system of the town. The system functions via heat exchangers so that the industrial water and the district heating water are kept separate.

5. THE EXPERIENCE OF KALUNDBORG.

What lessons can be learnt from the example of Kalundborg? Firstly, such an approach can lead to a significant reduction in the environmental impact, as is shown in Table 1 (Erkman, 1998):

Table 1: Environmental Aspects of the Symbiosis [Erkman, 1998].

Reduction in consumption of resources	
oil	45,000 tons/year
coal	15,000 tons/year
water	600,000 m^3/year
Reduction in waste emissions	
carbon dioxide	175,000 tons/year
sulfur dioxide	10,200 tons/year
Valorisation of "wastes"	
sulfur	4,500 tons/year
calcium sulfate (gypsum)	90,000 tons/year
fly ash (for cement etc)	130,000 tons/year

However, at what cost? The investment needed to put the different material and energy exchanges in place has been estimated at $75 million. This is the cost of the 18 projects established up to and including 1998. Keeping in mind that each exchange is based on a separate contract between the two partners involved, revenues can be estimated as coming from selling the waste material and from reduced costs for resources. The partners estimate that they have "saved" $160 million so far (Christensen, 1999). The payback time of a project is less than 5 years on average. Therefore a second lesson is that a more rational utilisation of resources can save money.

A third point is that the symbiosis in Kalundborg essentially "organised itself" over a relatively long period of time using sound financial criteria to decide which projects would be put in place. It is always tempting to want to re-engineer an industrial system in a "top-down" manner so that it becomes closer to a true ecosystem. As

Frosch has noted however (Frosch 1992), in such a carefully planned and integrated industrial system the individual parts would be too closely linked and dependent on each other, rendering it fragile and hence likely to collapse. He has expressed his preference for an industrial system that self-organises in order to accomplish the minimisation of waste, while recognising that there may be a need to help to "stock" the industrial ecosystem with certain types of company in order to create a better balance, either by providing information on business opportunities or supporting start-ups. Interestingly, although Kalundborg epitomises the self-organisation described by Frosch, it has in its turn been criticised by others for being fragile because it has too few partners and each is therefore too dependent on the others.

A fourth lesson is that the close proximity of the partner companies has undoubtedly helped in terms of reducing the cost of infrastructure to facilitate material exchanges, such as pipelines. However, it has also been pointed out that the proximity of the *human* partners was crucial in developing the co-operation needed to make the symbiosis work (Christensen, 1999).

These lessons from the Industrial Symbiosis can clearly be applied in an industrial estate with similar benefits. Côté and Hall (1995) have identified the following objectives for applying such an approach to industrial estates -

- Conservation of natural and financial resources
- Reduced production, material, energy, insurance and treatment costs and liabilities
- Improved operating efficiency, quality, population health and public image
- Potential income through the sale of waste materials.

6. CLOSING REMARKS.

Much of the existing literature about the Kalundborg example focuses on the Industrial Symbiosis and the By-Product Synergy projects. It is clear that such a project as the Industrial Symbiosis does not come about unless there is a basic awareness of the economic and environmental value of an effective environmental management programme.

We shall mention just one aspect of this awareness within one of the partners Novo Nordisk. Novo Nordisk is well known within the industrial community for the high quality of its environmental reporting. Its annual Environmental Report provides clear information on its resource and energy consumption as well as emissions and waste production. The data is presented for the company on a global basis and on a site basis. Comparison between different years allows the reader to assess the type of improvements that the environmental management system is bringing to the activities of the company. It is perhaps not surprising that Novo Nordisk participates in a WBCSD project on developing eco-efficiency indicators (see WBCSD, 2000 and Background Paper). It obviously has developed a great deal of expertise over the years in measuring environmental performance in its different production sites.

We see from this example that participation in the Industrial Symbiosis is not a unique experience for Novo Nordisk but is part of an overall environmental philosophy within the company.

7. REFERENCES.

Christensen, 1999 - J. Christensen, *Proceedings of the Industry & Environment Workshop*, held at the Indian Institute of Management, Ahmedabad, India, 1999.

Côté & Hall, 1995 - R. Côté and J. Hall, *J. Cleaner Prod*., 1995, 3(1-2), 41.

Erkman, 1998 - S. Erkman, *Vers une écologie industrielle*, Editions Charles Léopold Mayer, 1998.

Frosch, 1992 - R.A. Frosch, *Proc. Natl. Acad. Sci. USA*, 1992, 89, 800.

WBCSD, 2000 - www.wbcsd.ch; *Eco-efficiency Case Study Collection.*

8. FURTHER READING.

N. Gertler, *Industrial Ecosystems: Developing Sustainable Industrial Structures*, M.S. Thesis, M.I.T. 1995.

H. Grann, *The Industrial Symbiosis at Kalundborg, Denmark*, in *The Industrial Green Game*, D.J. Richards (ed.), National Academy Press, Washington, 1997.

The website of the Symbiosis Institute – www.symbiosis.dk