KALUNDBORG
SYMBIOSIS
The Kalundborg Symbiosis, 40th Anniversary

With this publication we take great pleasure in celebrating the 40th anniversary of Kalundborg Symbiosis, the world’s first large-scale Industrial Symbiosis. The Kalundborg Symbiosis exemplifies the idea that through collaboration it is possible to find common solutions to specific problems. This willingness for co-operation has given rise to a rather unique setup where resources are provided, and where waste streams can be shared and exploited for the mutual benefit of both the economy and the environment.

Kalundborg Symbiosis is a network run by various companies and it has enjoyed continuous growth and development over the last four decades. Today Kalundborg Symbiosis is made up of the Municipality of Kalundborg and seven privately held companies: Novo Nordisk, Novozymes, Statoil, DONG Energy, Saint-Gobain Gyproc, Kalundborg Forsyning, and Kara/Noveren.

With this publication we would like to tell the incredible story about how a local collaborative project run by passionate individuals ended up leaving its mark upon sustainable industrial development on a global scale, and helped promote Industrial Ecology and Industrial Symbiosis as an academic discipline. In retrospect we would also like to pay tribute to the many individuals who have contributed positively and unceasingly in many different ways and in various contexts to the development of Kalundborg’s Industrial Symbiosis.

The contributors to this publication are just some of those passionate individuals who over the years have worked with Kalundborg Symbiosis and have helped spread the message. Jan Hoff, Senior Vice President at Novo Nordisk, is the chairman of Kalundborg Symbiosis at a time with increased focus on resources, green growth and new circular business models. Against this
background we are seeing a renewed interest in Kalundborg Symbiosis not only on a national level, but also to a large extent internationally. Jan Hoff and his partners in Kalundborg Symbiosis have not only taken upon themselves the huge task of passing on this incredible story and the experience the various businesses have gained over the years in Kalundborg, but also of keeping focus upon further development of the cooperative relationships within the Symbiosis.

In his contribution Henrik Damm, Chief Executive Officer in the Municipality of Kalundborg and a member of the board of Kalundborg Symbiosis, also focuses on how the municipality is actively striving to be a facilitator for new symbiotic relations between the companies involved, and is using Kalundborg Symbiosis itself as an example of how sustainable change and green growth can flourish in a local community.

It is a great honour to have Jørgen Christensen, one of the early pioneers from Kalundborg Symbiosis as a contributor. Jørgen Christensen’s article is the nearest you can get to a birth certificate for Kalundborg Symbiosis. His first-hand account from the early years of the partnership provides us with a date for both the first symbiosis project and an explanation of how the Industrial Symbiosis got its name.

Marian Chertow, Associate Professor of Industrial Environmental Management from Yale University and President of the International Society of Industrial Ecology (ISIE), was one of the first to describe Kalundborg Symbiosis. Her coverage of Industrial Ecology and Industrial Symbiosis over the years has played a vital role in making Kalundborg Symbiosis perhaps the best-documented case of a functional Industrial Symbiosis.

Michele Rosano is director of the Sustainable Engineering Group at Curtin University and a very close friend of the Symbiosis Centre. Thanks to among others Michele and her team from Curtin
University, Australia can now boast of having not the world’s first, but the world’s largest Industrial Symbiosis located in the industrial park of Kwinana, south of Perth.

It is also a great pleasure to have Suk-Jin Yoon, Ph.D. from the Institute for Development Policy and Management, University of Manchester, among the contributors. The heightened attention and interest that Kalundborg Symbiosis is experiencing at this present time is to a very large extent represented by Asian delegations that make the long journey to Kalundborg to learn from the experiences that the companies have gained here. Suk-Jin Yoon’s contribution draws parallels from Kalundborg Symbiosis to one of the relatively new Industrial Symbioses, Banwol-Sihwa, a South Korean textile-dyeing conglomerate that has successfully implemented symbiotic co-operation among its partners.

Arne Remmen is professor and Deputy Head of Department of Development and Planning at Aalborg University. We are very pleased to include his contribution since it presents a personal account of the history of Kalundborg Symbiosis and traces the trends and developments in the Kalundborg Symbiosis over the years.

Last but by no means least; we would like to express our gratitude to the partner companies in Kalundborg Symbiosis for providing us with their expertise in telling the story of Kalundborg Symbiosis. Taken together these contributions provide an account of a unique model of collaboration which we hope can inspire others elsewhere to get involved and work with Industrial Symbioses.

On behalf of The Symbiosis Centre in Kalundborg,
Lisbeth Randers, director and Mette Skovbjerg, project manager
The concept of symbiosis is borrowed from the world of biology where a symbiotic relationship refers to the mutually beneficial cohabitation of individuals belonging to different species. The concept is an appropriate analogy for the special environment that exists in Kalundborg where eight very different business partners are co-operating to promote common values, both economically and environmentally.

An Industrial Symbiosis is a business relationship focused on sharing resources. This kind of co-operation reduces the total impact of the industry on the environment, and the individual businesses improve their bottom-line figures as well as their competitiveness.
With this publication we would like to draw attention to a very unique partnership that is being proclaimed nationally and internationally as an example of a transition towards a more sustainable society. But that is not the only thing that makes the Symbiosis special. At the same time it is also the story of how a local collaborative project, carried along by passionate individuals and founded on good relations between neighbours evolved and became a commendable example of how we in mutual trust can nurture sustainable and global industrial development where we safeguard our common, but limited natural resources.

The unique thing about the Kalundborg Symbiosis may have been the extensive pipeline system between the large production plants. Indeed, one could say that this whole ecosystem of reuse and optimised exploitation of resources has not been seen many places in the world. Equally unique, however, was the business culture that gave birth to many projects. The projects set a new standard for how companies entered into dialogue, discussed common challenges and found new, innovative solutions. A standard where openness and trust in the honest intentions of the other Symbiosis partners permeated the dialogue.

That culture is alive and well in the Kalundborg Symbiosis. It is our belief that we can help each other, and that we by virtue of the cohesion that the local community gives us, still have something
to contribute. It is a common premise to all of the enterprises involved in the Symbiosis that our collaboration should create value, not just for ourselves, but also for the area where our industries are located. In brief, we believe that we can find better solutions together instead of doing it on our own.

Throughout all these years the Municipality of Kalundborg has been an important co-operative partner by entering into dialogue with its partners in the Symbiosis in openness and trust. The municipality and the public enterprises have to a large extent been involved in creating new technical solutions, new forms of collaboration, and not least have facilitated the co-operation so that continuity and knowledge-sharing have been secured for more than 40 years.

Kalundborg Symbiosis is without doubt a system of pipelines and partnerships between production plants, but it is also an ongoing dialogue on important issues relating to the sustainable development of industry and the local community. For the last 40 years this dialogue has helped make the Symbiosis partners more robust economically and reduce the consumption of resources and thereby contributed to creating growth and employment in Kalundborg. It is our hope that with this publication we can spread this dialogue and inspire others to carry on working with Industrial Symbiosis, but in their own way of course.
JØRGEN CHRISTENSEN  
*Former Site Manager*  
Novo Nordisk

Jørgen Christensen graduated from the Danish Technical University with a Master’s Degree in Chemical Engineering, and was employed at various companies in the manufacturing industry from 1959 to 1997.

During this period, Jørgen Christensen worked for a/s Litex, a producer of seaweed extracts, and for Novo Nordisk A/S, a pharmaceutical/biotechnological company, where he held several leading positions in departments responsible for waste water treatment and plant administration.

He was also actively involved in several of the projects that gave birth to the Kalundborg Symbiosis. Until his retirement from Novo Nordisk in 1997, he was the General Manager of Novo Nordisk Biochemicals SpA in Italy.

Since 1997, he has been working as a consultant and a senior adviser. He has given lectures on the Kalundborg Symbiosis since 1989, at conferences all over the world. In 2009, Jørgen Christensen was Co-Convenor of the 6th Annual Industrial Symbiosis Research Symposium.
THE ANONYMOUS SYMBIOSIS (1972-1989)
The Industrial Symbiosis evolved by itself you might say. Quietly and anonymously. It wasn’t noticed by anyone, not even by those involved who were individually going about their daily jobs, trying to optimise the processes in their respective companies and improving their economy. The very first project involved setting up a cooling water supply from Lake Tissø to the new oil refinery which Dansk Veedol A/S built in Kalundborg in 1961 (later acquired by Esso and later again by Statoil). In fact it was not really a symbiosis project if you adhere strictly to the academic definition of the word, but nonetheless it became a platform for a number of projects later on. It was an unconventional collaboration between the refinery and the municipality to supply cooling water from Lake Tissø to the refinery. It involved untreated surface water, a product that is normally not on the market! A 13 km long pipeline was built and the financial backing was equally unconventional with Dansk Veedol extending the municipality a loan to build the pipeline.

The first real symbiosis project involved the delivery of excess gas from the refinery to the gypsum board plant built by Saint-Gobain Gyproc in 1972. Already during the project-planning phase the idea cropped up that some of the gas that was flared in the “eternal flame” of the refinery and thus wasted, could instead be used to dry the gypsum boards (the flame is also a necessary safety precaution). After many trials and teething troubles, and once things were up and running satisfactorily, an agreement

A PRINCIPLE WAS BORN

By JØRGEN CHRISTENSEN
Former Site Manager
was signed (September 1970) and a pipeline was laid. From 1972 and for many years afterwards, this first symbiosis collaboration remained in operation until the excess gas was replaced by other forms of energy.

Later, other co-operation projects emerged between the major industrial enterprises in the Kalundborg area. The Asnæs Power Station/DONG Energy was connected to the Tissø water supply and later began to reuse the cooling water of the refinery. Novo Nordisk found a way of utilising a major residual product (the so-called “Novo-sludge”, later to become NovoGro®), which could be used as a fertilizer on farmland. The power station at Asnæs soon positioned itself as a key player in these collaborate relations and ended up supplying energy and district heating to the town and steam to Novo Nordisk and the refinery. This project required good project coordination between the four parties concerned, but it also increased the awareness that there were significant advantages to thinking in terms of less conventional collaborations. That there lay a more general principle behind the co-operation only gradually became apparent; nonetheless communication between the companies increased and new projects emerged. By the end of the eighties twelve such projects were in operation.

A PRINCIPLE WAS GIVEN A NAME

In the meantime someone outside the industry had noticed what was going on. “The Environment Club”, which was part of the Development Initiative in Kalundborg and founded in 1988, was a discussion forum with participants from industry, the municipality, local government, agriculture and various environmental organisations. It was here that synergy between the various industries was discussed. Kalundborg sixth-form College had also noticed the development. At the end of the eighties, there was a lot of talk about the Brundtland report published in 1987 with its special focus on sustainability. In October 1989 the college organised a special project week during which the students split up into about 50 different groups and worked with topics that
in some way or other were related to the Brundtland report. There were also plenary sessions, including a debate panel on the relationship of industry to the environment where some of the major local companies participated in the panel. The evening before the panel debate, Valdemar Christensen (one of the managers at the Asnæs Power Station) was sitting at home and making preparations for the debate. His wife, Inge, made an analogy between this form of co-operation and the world of biology where different organisms work together in a symbiotic relationship. The analogy was obvious: The waste by-product of the one organism is the raw material of the other, and thus the name “The Industrial Symbiosis - Kalundborg Symbiosis” was conceived. People who were present at the time tell us that it was Inge who launched the “Symbiosis”, and Valdemar added the adjective “Industrial”. In any event, Inge wrote some time later a short poetical/philosophical book with the title “Symbiosis” which was illustrated by local artist Jack Lundsdal. Some of these illustrations were also printed as posters. You can still see them today hanging nicely framed on many walls in Kalundborg. The Industrial Symbiosis had become a cultural symbiosis too!

The Symbiosis has also done its bit in giving the people of the area a certain local pride. This could be seen on the streets that same year when all the companies involved in the project gave their employees Symbiosis t-shirts just before the summer vacation. The Environment Club followed up by organising its own local Symbiosis network.

THE STORY BEHIND THE STORY
The Industrial Symbiosis would never have happened if it had not been for the good communication between the companies involved, and it would never have drawn any attention without communication with the world outside. That is a story in itself. One of the many work groups at the sixth-form college had been studying how the local industries had been co-operating with each other and had made a table-sized cardboard model with the
various industries made of small cardboard boxes. The pipelines running between them were clearly marked using coloured string. The cardboard model drew a lot of attention, and the local newspaper, “Kalundborg Folkeblad” printed an article about it with a photo of the model. Not long afterwards one of the national newspapers printed a similar story.

After that the name “Industrial Symbiosis” began to appear in print, too. In November 1990 the Financial Times rang us up to learn more about the project. They sent journalist Peter Knight to Denmark. He then wrote an article which was widely read, the content of which inspired a number of articles in other media abroad. By the end of 1992 the Industrial Symbiosis had already become an established concept that had been presented at conferences in Herning, London, Kalundborg, Rio de Janeiro, Toronto, New York and Oslo, having received several environmental awards.

THE SYMBIOSIS CENTRE
The interest in the Symbiosis also manifested itself in the many enquiries and visits to the companies which initially were not prepared for such an influx of visitors. After recognising the need, and after much discussion for a few years, the Kalundborg Symbiosis Centre was finally established in 1996 as a project under the auspices of Kalundborg’s local trade council. The project was led by a steering committee consisting of representatives from all the companies involved in the Symbiosis. With just a minimum of staffing they were able to take care of answering enquiries, organising visits and giving lectures on the Industrial Symbiosis in Kalundborg, both in Denmark and abroad. Meanwhile the Symbiosis continued to slowly evolve throughout the nineties and knowledge of it gradually spread, albeit at a slow pace. Slowest perhaps in Denmark, where the interest was first kindled when Danes were able to read about the Symbiosis in foreign publications. It was only after 2010 that the development of the Symbiosis Centre seriously gathered momentum. This interest has also taken root politically which in turn has further increased the
interest of other businesses, and this has given rise to new related projects. We are sure that the future will add even more new and exciting chapters to the story of the Kalundborg Symbiosis.

FROM NAME TO BRAND
We have seen how the Industrial Symbiosis got its name and we have established that its “date of birth” was 11th October 1989. Later we saw how the name gained significance both for those involved and for the world at large. The name turned into a brand and this required communication. Gradually what people thought was just a “technology and environmental issue”, became a more general principle. Synonyms such as Circular Economy and Cradle-to-Cradle have since then appeared. All these concepts incorporate the principle of symbiosis as their common denominator. However, for these phenomena to thrive and flourish communication is necessary and that means personal contacts between people. Experience has taught us that communication is more important than technology and for this reason Industrial Symbiosis is a management discipline. Bear in mind that systems make things possible, but it is people that make things happen. This also holds true when things don’t always turn out quite the way one expected, and even when the Symbiosis partners had projects that lay outside their main focus, their primary production. Unplanned initiatives succeeded and efficient communication generated more initiatives. From this a mindset and a name came into being. The name generated interest and evolved into a brand. People around the world now associate Industrial Symbiosis with Kalundborg. But it was to take more than 40 years!
EFFICIENT ENERGY UTILISATION

RASMUS FINNERUP WILLE
Managing Director and CEO
Statoil Refining Denmark A/S

The Industrial Symbiosis is of great importance to Statoil Refining Denmark as it helps to reinforce the green image of the refinery.

In the refinery industry there are many different competitive parameters, one of which is energy efficiency. Statoil’s refinery in Kalundborg is a world leader in this area and Kalundborg Symbiosis is helping us to ensure that.

Instead of using energy ourselves to produce steam, we made an agreement with DONG ENERGY Asnæs Power Station for sharing the steam supply that DONG Energy provides to a number of other Symbiosis partners. Likewise, Asnæs Power Station is making use of the refinery’s cooling water. Since we do not produce the steam ourselves, we are reducing our total consumption of energy.
HENRIK DAMM
Municipal Chief Executive Officer
Kalundborg Municipality

Henrik Damm has a Master’s Degree in Political Science and has held several executive positions in Danish local government and a number of Danish municipalities. He joined Kalundborg Municipality in June 2008. In addition to his daily job, Henrik Damm has taught Employment Law at the Danish Association of Masters and PhDs, and Pay and Employment Conditions at the local government training centre.

Henrik Damm is a chief executive officer at Kalundborg Municipality, also known as “the Green Industrial Municipality”, whose vision is to create sustainable growth through innovation, new technology and better utilisation of resources, based on the symbiosis philosophy.
New York has its Statue of Liberty, Venice has the Bridge of Sighs, Copenhagen has the Little Mermaid, but in Kalundborg we have the Kalundborg Symbiosis! The world’s first Industrial Symbiosis is a textbook example of how industry has evolved in a local community that both earns money and safeguards the environment. The interest outside Kalundborg has been enormous over the years, and at the Symbiosis Centre they have welcomed guests from near and far. Particularly the latter since there seems to be an inversely proportional relationship between interest and geographical location. The further away the visitors came, the more they seemed to know about Industrial Symbiosis, and the more enthusiastic they were! The visitors came and saw the Industrial Symbiosis and departed again happy, and Kalundborg continued to develop its Symbiosis way of thinking.

And that is no mean achievement. Kalundborg has Zealand’s largest concentration of industries outside Copenhagen just as some of the country’s largest energy and process industries and major pharmaceutical and medical companies are to be found near here. In other words, Kalundborg has the upper hand with regard to future growth. The industries in Kalundborg have cracked the code by minimising production costs through co-operation and increased resource and energy awareness.

Kalundborg Municipality has given itself the task of exploiting the position of Kalundborg Symbiosis as a kind of regional beacon, to
make the town more than a mere passing tourist attraction. In the industrial and development policy for 2011-2014 this vision was expressed as follows:

"We want to create sustainable growth through increased focus on innovation, new technology and better resource efficiency through symbiosis thinking. Kalundborg Municipality is playing an active role in the transition to a climate-friendly and energy-efficient community independent of fossil energy sources with a constant focus upon exploiting and testing possibilities in new green technologies."

The municipality plays a proactive role; by emphasising the good example that it really is possible to generate sustainable growth, we are encouraging collaboration between administration and industry in a completely new way. On the one hand the city administration needs a regulatory role in relation to local industry so that concerns for the environment and the interests of the citizens are taken into account, but on the other hand it also has to enter into a constructive dialogue on how resources can be used in the best possible way. Sometimes this requires thinking outside the box and initiating other collaboration models than traditional ones. The principles of the symbiosis philosophy, founded upon sincerity and trust have taught us exactly this: there is a fruitful path to follow, one that generates value for all parties concerned.

The co-operation between the companies and the local politicians is also an important factor to bear in mind. This mutual respect for each other has a solid political foundation and helps provide a stable framework for business development. Businesses, politicians and citizens alike all share a common responsibility in creating a sustainable local community. Only when we stand together will our mission succeed in reducing CO2-emission, for example. It is a tough haul and no walk in the park, but the collaboration from Kalundborg Symbiosis teaches us that it bears fruit; the companies have succeeded in reducing their CO2-emission significantly, without loss of jobs or productivity.
Kalundborg faces some special challenges with respect to future growth on account of its geographical location. Our deep seaport allows access to ship transport and is at the same time a production platform for many major industries. In itself that is an enormous potential which is difficult to exploit if the infrastructure on land does not keep up. In this context we would like the Danish state to give us a helping hand by extending the motorway network all the way to Kalundborg and provide a faster train connection to Copenhagen because growth in Kalundborg is of benefit to the whole of Denmark!

The Green Industrial Municipality houses a number of projects that all focus on green growth and climate-friendly solutions, such as Inbicon, Dong Energy’s second generation bioethanol plant, the E4Water test and demonstration facility for waste water treatment with microalgae; Smart City Kalundborg, an ambitious grid project that will demonstrate in real life how a city can achieve optimum energy efficiency, Bioenergi Sjælland that analyses potentials for further bioenergy production in Region Zealand; and the Symbiosis Centre established to create new symbiotic relations between companies in the region. The projects are completely different in scope, involve totally different players, but common to all of them is that they each in their own way are working to implement and convert their theoretical knowledge of green growth into something that can have practical implementation. The projects and the various testing and demonstration facilities are helping to put Kalundborg on the map as a site where potential for industrial growth can be tested before being implemented on a full scale. It is our vision that even more Danish and international companies will choose to settle in Kalundborg because of our dynamic and creative environment.

Growth and climate-friendly solutions need not be in contradiction to one another, but can actually go hand in hand and create new jobs. In 2012 alone, 230 new private-sector jobs were created in Kalundborg Municipality, which is exceptional in a time where the
tendency is just the opposite. As a municipality it is important to us not only to be involved in providing the framework for creating more jobs, but also to attract new citizens who would like to live in the area. Kalundborg has many qualities to boast of and we would like to invite new citizens to come and take a closer look because we have a town that is green in more respects that just the industrial one!

All in all we are committed to laying the foundation for a “whole life”. The social cohesion, the local involvement and the sense of common responsibility set the agenda in two exciting projects. In co-operation with Danish Architecture Centre and a number of municipalities and state-run institutions, we are setting the future stage for a society independent of fossil fuels. How can we extend the symbiosis mindset of mutual advantages so it encompasses urban development, the relationship between urban and rural areas, infrastructure, family life and many other things?

The second project deals with how we can promote the sustainable development of Kalundborg Municipality when we take into account parameters such as health, education, biodiversity, leisure activities and economy. In co-operation with local industry, Kalundborg Municipality is pinpointing specific areas that require special attention so that development can proceed in a sustainable manner.

Through collaboration with our external partners we hope to gain fresh inspiration for continual development of our region. As a municipality we would like to provide ideal framework conditions not only for industry at large, but also for our citizens so Kalundborg can be an attractive place to be, both with regard to production, accommodation and employment. The Kalundborg Symbiosis has taught us to open our eyes and look around, to co-operate and trust those who at first glance may not resemble us. The Industrial Symbiosis put Kalundborg on the global map 40 years ago and this Green Industrial Municipality is still hard at work maintaining its focus and ongoing development!
ACCESS TO RESOURCES AND A STRONGER GREEN IMAGE

NIELS CHRISTIAN KJÆR
Director
DONG Energy A/S Production Region East

DONG Energy Power Station has been involved in the Kalundborg Symbiosis right from the very beginning; it is an important collaboration that has developed over the years. In our experience this collaboration has always been particularly positive and through it we have formed close ties with neighbouring industries and the local community, and have been given opportunities to optimise our business.

At Asnæs Power Station what we call a by-product has turned out to be a rather valuable asset in the context of Symbiosis through which we can both sell and buy materials. For instance, the water we take from Statoil Refining Denmark has been of great benefit to us. This gives us access to resources and strengthens our green image as well.

In 2007 DONG Energy had to find a suitable location for our two biomass testing facilities, Inbicon and Pyroneer, a bioethanol manufacturing plant and a regasification plant respectively. The natural choice fell upon the Asnæs Power Station in Kalundborg, partly because we owned the site, and partly because we had a power plant unit that was suitable for use with the gasifier at the Pyroneer plant. Furthermore, Kalundborg Symbiosis has enabled a closer co-operation with the local farmers on the supply of straw for Inbicon, and in return we provide them with fertiliser in the form of molasses. The optimal solution for us has been to construct two testing facilities so they could be part of the Symbiosis and contribute to the valuable co-operation with the region.
MARIAN CHERTOW
Professor
School of Forestry and Environmental studies
Yale University

Marian Chertow is an Associate Professor of Industrial Environmental Management and has been the Director of the Industrial Environmental Management Program at the Yale School of Forestry and Environmental Studies since 1991. Her research and teaching focus on industrial ecology, business/environment issues, waste management as well as environmental technology innovation. Primary research interests are 1) The study of Industrial Symbiosis including geographically-based exchanges of wastes, materials, energy, and water within networks of businesses. 2) The potential of industrial ecology to underpin ideas of the proposed Circular Economy law in China. 3) The application of innovation theory to the development of environmental and energy technology.

Marian is on the Editorial Board of BioCycle Magazine and the Journal of Industrial Ecology, the Board of the Eco-Industrial Development Council as well as on the Advisory Board of the Connecticut Clean Energy Fund, which develops renewable energy projects to increase the availability of green energy. Marian serves on the founding faculty of the Masters of Science in Environmental Management Program at the National University of Singapore where she teaches “Business and Environment” and is a Visiting Professor at Nankai University National Center for Innovation Research on Circular Economy in China.
The Kalundborg Symbiosis has inspired a great deal of academic reflection and forward motion – especially over the last 20 years. It is one of the foundations of the growing field of Industrial Ecology and it is described in many academic languages from engineering to landscape architecture to organizational behaviour to complex systems science. The 40th anniversary celebrates how all of this came about and raises the question: What else will spring forth from the depth, breadth, and height of this small town marvel?

I currently serve as the President of the International Society of Industrial Ecology (ISIE). Looking back, the first great contemporary article in what became our field was written in 1989 by two experts at General Motors in the popular journal, *Scientific American*. To improve manufacturing, these authors wrote: “Waste from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment.” Curiously, in the same year the “industrial ecosystem” described in theory by Frosch and Gallopoulos was found in practice in Kalundborg and shortly thereafter announced with two articles in the *Financial Times*. Soon, academics from all over the world began to pay attention. Ever since, we have been learning new lessons about what is achievable in the realm of sustainable industrial development and cooperative business practice if the Kalundborg Symbiosis model is closely observed from a system’s perspective as it adapts to internal and external change.
Curiosity about the Kalundborg Symbiosis has driven many academic questions and debates such as:

1. To what extent was Kalundborg planned and to what extent was it self-organized such so we did not really even “uncover” it as a system until almost halfway through those forty years?

2. To what extent does the Kalundborg Symbiosis function more like an industrial park than a social network?

3. Is the Kalundborg Symbiosis replicable?

4. Can the Kalundborg Symbiosis be framed as a collective action problem?

5. How does firm embeddedness and industrial collaboration change over time?

6. Is there a natural lifecycle of an industrial ecosystem after which it will devolve?

7. Does the interdependence among the companies constrain technological innovation and the prevention of pollution?

Perhaps, the most astonishing aspect to symbiosis watchers is the extent to which Kalundborg has evolved and continues doing so. Nicholas Gertler pointed out an evolution from simple links across companies such as the sale of waste products without any significant pre-treatment or rerouting – including flue gas, fly ash, and steam – to later, more evolved ones growing out of pollution control that required altering processes and by-products such as Novo Nordisk sludge and scrubbed SO2 at Statoil and the power plant to make fertilisers and synthetic gypsum. Today, we could add another progression: Not only did the emphasis on reuse of by-products from industrial processes grow from simple to more
complex. The next wave of evolution remakes the raw materials of the production including bioethanol manufacture from local straw and enzymes at Inbicon, and they can move toward replacing imported coal at Asnæs Power Station with local biomass fuel in collaboration with Pyroneer. Relating this to theoretical observations from the complex systems literature draws in the work of ecologist James Kay who observed that “as ecosystems develop or mature, they should develop more complex structures and processes with greater diversity, more cycling, and more hierarchical levels to aid exergy degradation” Kay (2000, 76).

Scholars including Noel Jacobsen, Frank Boons, Leo Baas and Weslynnie Ashton examined the idea that social capital played a significant role as an enabler of what former Novo Nordisk leader Jørgen Christensen labelled the “short mental distance” among individual actors in Kalundborg. Social capital was expressed through institutions such as the Rotary Club, and then the formation of the Environment Club composed of senior facility managers in Kalundborg in the 1980s followed by the formation of the Symbiosis Centre in 1996 to seek economic development through further adoption of industrial exchanges. When I made my first visit to Kalundborg in 1998, however, I learned that the founding generation of managers thought that the biggest risk to the industrial ecosystem’s longevity is with the next generation of managers. The founders were concerned that joining the social network of industrial partners would be less of a priority to newly appointed managers at the key industrial companies. Typically brought in from other parts of Europe, the worry was that these individuals would not feel the same necessity or commitment to “buy-in” to this cooperative cultural phenomenon.

Fifteen years after my first visit, we see substantial participation from the long-term partners with several new organizations joining the Symbiosis. We also see foundational changes that could have shaken the whole system if it were fragile. Instead the overall resilience of the industrial ecosystem has been maintained.
Thus, the Kalundborg Symbiosis not only has a strong record of accomplishment in achieving substantial environmental and economic savings. Over time, it has withstood at least three types of disturbance, too:

1. changes in footprint, including doubling the size of the oil refinery,

2. changes in flows, including two switches in fuel at the power plant intended to reduce coal dependency, modification in composition of sulfur residue after process improvements in the refinery, and the establishment of a water basin that fully reorganized water flows for the key industrial companies,

3. changes in organizations, including shifts in corporate ownership at the gypsum board plant and the division of the pharmaceutical plant into two separate companies.

So continued evolution is a headline story for Kalundborg Symbiosis. At the level of a single link, it is easy to think that when an exchange is discontinued, it is a failure. Yet, matter is not created or destroyed in Kalundborg, so in these cases, it is put to other uses. Most recently, the yeast slurry formerly sent to regional pig farmers as a by-product of insulin production at Novo Nordisk is now being sent for processing in the new bioethanol plant. Thus, a link that began in 1989 has been repurposed 23 years later. At the systems level, the quantity and quality of relationships among the participants have allowed an increasing diversity and experimentation in the system.

Even with all of the celebrity and admiration for the Kalundborg Symbiosis, more research is needed, especially to understand its nature as a self-organizing system. Large and powerful symbiosis hotbeds in East Asia, for example, rely more on system planning but still find spontaneous growth to be a significant pathway. Through
their studies of the National Industrial Symbiosis Programme in the UK, Howard-Grenville and Paquin have introduced the notion of orchestrated networks to the Industrial Symbiosis literature. Still, more empirical work is needed to specify environmental and economic savings in greater detail as well as costs and benefits for the industrial partners. In total – spatially, temporally, organizationally – there may be a generational lifecycle of industrial ecosystems that we have not yet fully encountered and described. So ever onward, Kalundborg Symbiosis! You have provided many new branches to the ultimate tree of knowledge over more than a generation.
RELATED READINGS


Frosch, R.A., & Gallopoulos, N.E. 1989. Strategies for Manufacturing. *Scientific American* 266: 144-152.


FINDING INNOVATIVE SOLUTIONS TOGETHER

HANS-MARTIN FRIIS MØLLER
CEO
Kalundborg Forsyning A/S

As a public owned company we have a local obligation to the citizens of the municipality and a duty to safeguard its interests in business development. It has been of great importance to Kalundborg Forsyning (the local water and heat supplier) that agreements in the Kalundborg Symbiosis should be based upon the same technical and economic foundations and that the collaboration with the partner industries should not burden the other customers with extra expenses or cause technical difficulties.

The participation in Kalundborg Symbiosis and the close dialogue with the local industry have made Kalundborg Forsyning a trustworthy business partner with employees who think innovatively and creatively when solutions need to be found that support an optimisation of both economy and environment.

For us the benefit of a close dialogue with the local industry is that we have become an interesting, challenging and developing public workplace with specialized plants that are utilised optimally and operated to the best of current available knowledge. The dialogue and the co-operative culture enable Kalundborg Forsyning to contribute significantly when it comes to attracting new businesses and retaining existing ones.
Suk-Jin Yoon is a PhD student, and has recently completed his doctoral thesis at the Institute for Development Policy and Management, University of Manchester. His PhD thesis “Environmental Performance of Clustered Firms” seeks to establish a link between the Industrial Ecology literature and the industrial cluster literature by drawing on empirical evidence from the textile-dyeing industry and the petrochemical industry in South Korea.

Prior to his PhD research, he served as an NGO activist for workers’ health and environment in industrial areas. He also worked for two government research institutes: Korea Institute of Public Administration and Korea Research Institute for Vocational Education and Training. His current research focuses on small enterprise clusters, innovation systems and environmental upgrading in global production networks.
INTRODUCTION
40 years of industrial symbiosis development in Kalundborg, Denmark, has inspired many policy-makers, business people, and scholars. Ever since the Kalundborg model labelled itself using ecological metaphors, a growing number of symbiosis-like networks have sprung up globally (Chertow 2007). As a result, we now recognise that there exist various types of industrial sites that can be categorised as industrial symbioses. This present article introduces a newly developed industrial symbiosis model located in the Banwol-Sihwa textile dyeing cluster, South Korea. The story from the Banwol-Sihwa dyeing cluster provides some interesting points of comparison with the Kalundborg Symbiosis. This article presents a series of dialogues between the Korean model and the Danish model that are respectively labelled as industrial cluster and Industrial Symbiosis.

DEFINITION OF INDUSTRIAL SYMBIOSIS AND INDUSTRIAL CLUSTER
To begin with, it may be worthwhile to look over similarities and differences between the two concepts; Industrial Symbiosis and industrial cluster. Chertow (2007: 12) defines Industrial Symbiosis as “engaging traditionally separate industries in a collective
approach to competitive advantage involving physical exchange of materials, energy, water, and by-products.” The typical networks are by-product exchange, infrastructure-sharing and shared services. The term Eco-Industrial Park (EIP) is also a synonym for Industrial Symbiosis. Strictly speaking, the EIP concept is more focused on geographical proximity than Industrial Symbiosis. On the other hand, an industrial cluster can be defined as a geographic concentration of interconnected companies (Porter 1998). The industrial cluster literature argues that firms can enjoy passive gains like economies of scale as well as organise joint actions (Schmitz 1995; Schmitz and Nadvi 1999). In this respect, the three types of symbiosis network can also be understood as joint actions of clustered firms.

Although both concepts focus on the collective behaviours of agglomerated firms, there are three main differences. Firstly, while an Industrial Symbiosis originates from an inter-sector dimension; an industrial cluster is intra-sector in nature. Secondly, while Industrial Symbiosis is a by-product and energy-cascading network, industrial cluster is more related to main production networks. Lastly, while most case studies on Industrial Symbiosis have tended to focus on large companies, the literature on industrial clusters and industrial districts has placed a great deal of emphasis on small companies. Kalundborg Symbiosis and the Banwol-Sihwa dyeing cluster obviously represent these differences. Kalundborg Symbiosis encompasses a set of by-product exchanges between several large companies working in heterogeneous industrial sectors. On the other hand, the Banwol-Sihwa dyeing cluster is an agglomeration of about 80 small and medium-sized dyeing and printing companies engaged in the same industrial sector.

THE BANWOL-SIHWA DYING CLUSTER IN SYMBIOTIC EVOLUTION
The Banwol-Sihwa dyeing cluster is located in a huge industrial area near the coast, the Banwol-Sihwa Industrial Complex. The dyeing and printing mills are situated within the limited spatial boundary,
sharing infrastructures, labour pool, information and ancillary services. They have been participating in the EIP programme from the outset since the Korean government launched the programme in 2006 and are currently engaged in three Industrial Symbioses.

The first Industrial Symbiosis involves a waste water heat exchange between two common effluent treatment plants and their neighbouring cogeneration plants. As the effluent is processed through the heating system called heat pump, the waste water heat is used as an energy source by the cogeneration plants and the cogeneration plants supply steam heat back to the dyeing cluster. The second symbiosis network provides effluent sludge to a cement manufacturing company as a substitute for clay. The other Industrial Symbiosis collects and reuses oil ingredients contained in the air pollutant emitted from textile dyeing and printing units. A pilot by-product supply chain between a dyeing firm and a used-oil refinery firm is being tested.

The Banwol-Sihwa dyeing cluster and Kalundborg Symbiosis are very different from each other in almost all respects. In a sense, the only single feature the two firm agglomerations share in common is the fact that they are involved in Industrial Symbiosis networks and can therefore be labelled as Industrial Ecology. How have these two very different industrial sites reached such similar environmental results? The answers become apparent in the three dialogues below between the Western model and the Asian model.

THE FIRST DIALOGUE: PHYSICAL AND INDUSTRIAL CIRCUMSTANCES
Kalundborg is a small industrial town where several major industries are located in close proximity. The main industries are DONG Energy/Asnæs Power Station, the largest power plant in Denmark, Statoil, a large oil refinery, Novo Nordisk, a multinational pharmaceuticals maker, and Saint Gobain Gyproc, a plasterboard manufacturer. Given that waste stream is a distinctive feature of the energy-generation, petrochemical and chemical sectors, the
potential of Industrial Symbiosis was inherent in this industrial setting of Kalundborg. Furthermore, it is important to bear in mind that the companies involved in the symbiosis networks in Kalundborg are large production units. The volume of by-products generated from one unit is sufficient enough to guarantee the economic feasibility for its symbiosis counterparts in Kalundborg. Not only that, one should be aware that water is a rare natural resource in Kalundborg. It was initially the chronic shortage of water that motivated local businesses to initiate the symbiosis networks (van Berkel 2009).

The Korean dyeing and printing companies also faced a water issue but in a different way. The Han River that flows through the capital city, Seoul, was seriously contaminated in the 1970s by the pollution caused by certain manufacturing industries such as the textile dyeing sector located along the river; consequently the South Korean government ordered these companies to leave Seoul in 1976. In response to this harsh government regulation, they made a collective decision to mass migrate to the Banwol-Sihwa area, build common effluent treatment plants (CEPT), establish business cooperatives, the Banwol Dyeing Enterprise Cooperative (BDEC) and the Sihwa Dyeing Enterprise Cooperative (SDEC), both specialised in providing environmental management services, and co-locate with cogeneration plants which supply steam to the dyeing cluster. As a result, the dyeing and printing companies have established the physical conditions favourable for the Industrial Symbiosis networks. Because they treat effluent collectively through the CEPTs, the volume of by-products is sufficient enough to be reused by the symbiosis counterparts despite their small production scale. Moreover, the existence of the neighbouring energy-generation facilities gives an advantage for the Industrial Symbiosis just as in Kalundborg.

THE SECOND DIALOGUE: THE SOCIOCULTURAL CIRCUMSTANCES
The most intriguing aspect about the Kalundborg Symbiosis is that the Kalundborg model has developed without any overall
The business structure in Kalundborg is composed of heterogeneous industrial sectors that are not necessarily in an input-output relation. If so, how did the inter-firm co-operation develop so well in Kalundborg? In fact, the business culture of an industrial area is not only determined by market circumstances, but also by other elements such as social relationships. The uniqueness of sociocultural relationships among the business people in Kalundborg is another key to the successful Industrial Symbiosis. The high-level managers, engineers and other workers lived together within a small town. Although they worked for different companies, they shared the same memberships of the town-based social clubs, and their children attended the same schools (Interview with Kalundborg Symbiosis Centre). Naturally, they have had many opportunities to talk with each other and share ideas about their common issues. In a more academic sense, the firms located in Kalundborg are embedded in the local community. This phenomenon has been highlighted as a source for ‘trust’ in economic relations in the industrial districts and industrial cluster literature (Becatiini 1990; Dei Otatti 1994; Nadvi 1999) as has the term ‘mental distance in Industrial Ecology literature (Ashton and Bain, 2012; Chertow 2000; Ehrenfeld and Gertler 1997). Arguably, the integration of the local industry and the residential community in Kalundborg has created the sociocultural background where business people can co-operate and make the right choices.

As for the Banwol-Sihwa dyeing cluster, its symbiotic networks are also grounded in social ties, but such social ties are much more business-oriented relationships. As a typical industrial cluster, the dyeing and printing firms in Banwol-Sihwa have been doing many joint actions such as group purchase of raw materials, international marketing, personnel training, infrastructure sharing and research and development activities. Through these joint actions, the dyeing and printing firms have formed strong bonds between BDEC and SDEC. A high degree of trust and openness among the dyeing and printing firms has been built through a long history of joint actions and, as a part of their joint actions,
they have entrusted the collective representation pertaining to environmental management to the two enterprise associations. According to the Interviews with the Gyeonggi EIP Centre and Korea Institute of Industrial Technology that have involved in establishing the Industrial Symbiosis networks of the Banwol-Sihwa dyeing cluster frequently point out that the strong intra-sector bonds and the collective social representation are some of the most favourable conditions for the EIP initiative in the Banwol-Sihwa dyeing cluster. However, these types of intra-sector ties do not necessarily guarantee an Industrial Symbiosis which is basically an inter-sector network. Moreover, the Banwol-Sihwa dyeing cluster is far less interactive with the residential community compared to the Kalundborg Symbiosis. This suggests that something other than sociocultural circumstances has played a role in facilitating inter-sector co-operation in Banwol-Sihwa.

THE THIRD DIALOGUE: POLITICAL CIRCUMSTANCES
Kalundborg Symbiosis has evolved without specific policy or political impetus. The local institutions like Kalundborg Symbiosis Centre have emerged recently in order to disseminate the experience from Kalundborg and expand symbiosis networks to other areas after the Kalundborg model has developed over the last 40 years in its own way. Although non-business institutions like Kalundborg Municipality are engaged in the symbiosis networks, they have acted as a participant rather than a coordinator. Ehrenfeld and Gertler (1997) suggest that the characteristics of the Danish regulatory system are one of the key elements to the success in Kalundborg. The regulatory requirements are consultative so that firms can have the flexibility in managing their environmental issues. The national-level institutional setting in Denmark has contributed as it were to the development of Kalundborg Symbiosis.

The Korean EIP programme is a national-level decision. Accordingly, it can be said that the central government has changed the regulatory framework in a favourable manner for Industrial
Symbiosis. Regarding the Banwol-Sihwa dyeing cluster, the more important circumstance is the local-level institutional setting. As mentioned before, the cluster is situated in the national industrial district, the Banwol-Sihwa Industrial Complex. There are many other industries and various public institutions like governmental agencies, innovation centres and local universities in Banwol-Sihwa. In general, small firms like the dyeing and printing firms located in Banwol-Sihwa have little financial and technical capacity. Accordingly, the dyeing and printing firms have co-operated with the public institutions in order to maintain their competitiveness. This partnership has also played an important part in establishing the Industrial Symbiosis networks of the dyeing cluster. Gyeonggi EIP Centre, a public agent specialised in implementing the EIP initiative at the local level, has functioned as a network broker to co-ordinate inter-sector networking, and Korea Institute of Industrial Technology and Korea Testing Laboratory, local public research institutes, have acted as knowledge-providers. With the co-operation of these local institutions, the Banwol-Sihwa dyeing cluster has developed into Industrial Symbiosis networks.

Concluding remarks: Toward the Diversity of Industrial Symbiosis
Although both the Kalundborg model and the Banwol-Sihwa model can be described as Industrial Ecology, their symbiosis networks have evolved out of very different circumstances. While Kalundborg Symbiosis is an agglomeration of several major industries working in the heterogeneous industrial sector, the Banwol-Sihwa dyeing cluster is a clustering of small and medium-sized companies working in the same industry. While Kalundborg Symbiosis developed from its unique sociocultural circumstances, the Industrial Symbiosis of the Banwol-Sihwa dyeing cluster has relied heavily on the local institutional settings.

Kalundborg cannot be regarded as a conventional type of industrial cluster in the academic sense because it consists of large companies and heterogeneous industrial sectors. However, the achievement in Kalundborg provides a crucial lesson that
environment-friendly proactive collaborative projects are not necessarily limited to one sector boundary. The Banwol-Sihwa dyeing cluster provides another lesson that a conventional cluster can also develop Industrial Symbiosis synergies. The small dyeing and printing mills realise the economic feasibility of by-product exchanges via collective waste treatment and create new input-output relationships with different industrial sectors. Together, the Kalundborg model and the Banwol-Sihwa model demonstrate the diversity of industrial structures where Industrial Symbiosis can be situated and the potential for theoretical bridging between Industrial Ecology literature and industrial districts literature.

According to the knowledge dissemination from Kalundborg and world-wide, it is now arguable that Industrial Symbiosis can be seen as a global phenomenon. Naturally, we have faced an interesting issue that was not recognised in the early days of the Industrial Ecology literature, the diversity of Industrial Symbiosis. As van Berkel (2009; 483) points out, the number of uncovered Industrial Symbioses may be just “the tip of the iceberg”. One plain fact is that the diversity will provide more lessons for the Industrial Symbiosis development. Therefore, it is clear that we need more dialogues beyond the geographical and theoretical borders in order to learn from each other.
REFERENCES


Like with good neighbours, the partnership in Kalundborg Symbiosis is based on participants who actively invest time and resources in the relationship. We invest because through the good and open dialogue we believe that we get something in return.

Kalundborg Symbiosis is a success because the companies involved as well as the Kalundborg Municipality go through great efforts to find solutions that benefit all parties. We spend more time finding solutions than discussing how to share the benefit. That’s what it takes to find the best solutions.

With its 2,400 employees, the production site at Kalundborg is the largest within Novo Nordisk, and we produce half of the insulin used worldwide. Insulin production on that scale obviously requires many resources, and the Industrial Symbiosis contributes to creating a more sustainable production, thus ensuring that we will be able to maintain, and maybe even expand, our activities in Kalundborg in times to come.

To Novo Nordisk, Kalundborg Symbiosis has been the forerunner of what has now become a tradition of forming partnerships. In recent years, more partnerships have emerged. To us, this is the natural result of a good relationship between neighbours. We are willing to seek new opportunities, breaking down barriers and testing new ideas - and with good partners we usually succeed.
Doctor Michele Rosano is the Director of the Sustainable Engineering Group (SEG) at Curtin University, Perth Western Australia. She has a PhD in Resource Economics from the University of Western Australia. Michele is a resource economist with particular research interests in life cycle assessment, resource economic modelling and sustainability metrics.

Michele has worked internationally in the mining industry in a number of senior executive positions in London, Japan and Singapore and as a lecturer and researcher in Australia. She is currently leading a number of Industrial Ecology research projects in industrial by-product re-use, waste management, engineering sustainability education and life cycle assessment.

SEG was established with the support from Curtin University to promote the uptake of Industrial Ecology and waste minimisation activities in Western Australia. The Sustainable Engineering Group is internationally renowned for the Industrial Symbiosis research carried out in Kwinana Western Australia, and it has successfully developed other regional synergies programs including Gladstone, Queensland and Rustenburg South Africa and recently Whyalla in South Australia.
How do you define and describe Industrial Symbiosis?
Industrial Symbiosis involves the exchange of materials, water, energy, by-products and supply chain services among organisations who are in close proximity and who benefit from the collaboration and synergies developed. The exchanges/synergies developed often provide significant environmental benefits, for example through increasing energy efficiency with power, co-generation and by-product reuse, recycling waste waters to reduce overall water consumption and in the joint planning of utility and transport networks that provide more sustainable options, particularly in regional development scenarios.

Did you study the case of Kalundborg Symbiosis and was it helpful to you in terms of road mapping new areas?
Kalundborg Symbiosis is considered by many to be the ‘mother of Industrial Symbiosis’ as it was one of the first large Industrial Symbiosis programs. Furthermore, over the past 40 years since its inauguration, it has continued to evolve and add further economic and environmental benefits to both the industry involved and the local community. The scale of water and resource use savings in Kalundborg was certainly instrumental in encouraging the development of an Industrial Symbiosis program in Kwinana.

The Kwinana symbiosis program was established to develop synergy opportunities and communicate the associated improvements in overall environmental management and eco-
efficiency to the local area. Like the Kalundborg Industrial Symbiosis program, one of the major synergy focuses of the Kwinana symbiosis project was in further improvement in energy recovery and water recycling through joint industry initiatives.

Which role does the local context in your perspective play in order to establish and develop Industrial Symbiosis?

The Kwinana Industrial Area (KIA) was established in the 1950’s to accommodate the development of major resource processing industries in Western Australia. For the past 60 years, the KIA has been Western Australia’s most significant heavy industrial region and is adjacent to a thriving suburban precinct and a sensitive marine environment.

In 1991, the Kwinana Industries Council (KIC) was established by core industries in the KIA to manage the required air and water monitoring for the KIA in response to increased government and community pressure to manage the air- and watersheds, and protect the sensitive marine environment in the adjacent Cockburn Sound.

In 2001, the Kwinana Industries Synergies Program was initiated to develop more symbiotic linkages in the KIA and to assist it in its development as an Eco-industrial park. During the 8-year symbiosis program, 106 synergies were developed, including 68 between core process industries and 38 with service and infrastructure industries. These synergies resulted in significant economic and environmental gains for the industries involved and sought to address a broad range of environmental and growth issues common to Kwinana’s major industries, whilst seeking to foster positive interactions between member companies and between industry and the broader community.

The development of a Sustainability Roadmap was the next step for the KIA in further developing its sustainability credentials as a leading Eco-Industrial park. The KIA Sustainability Roadmap
was intended to provide a decision-making tool for assessing and benchmarking the KIA’s sustainability achievements and to provide a map for guiding the KIA’s future sustainability efforts. A matrix of different sustainability indicators forms the core of the Sustainability Roadmap and provides individual targeted performance metrics in managing sustainability performance over the longer term. Sustainability indicator measures include recycled water use, GHG production, number of Industrial Symbiosis synergies developed between participants and total energy use per economic output. The achievement of these indicator targets will go a long way in providing more sustainable performance outcomes for the KIA and in highlighting the direct economic and environmental benefits associated with Industrial Symbiosis programs, too.
KARA/NOVEREN is one of Denmark’s largest waste management companies. It is owned by nine municipalities, one of which is the municipality of Kalundborg, with a total population of 400,000 and over 20,500 businesses. Our primary task is to make best use of the resources found in the waste from private households and businesses in a cost-effective way to benefit the environment. 14 civic amenity sites in and around the area are responsible for efficient handling of 140,000 tons of waste generated each year by private households and local businesses. 98% of the collected material is re-used or utilised for energy production.

Our business is converting the types of waste that cannot be recycled into electricity or district heating. In 2013 KARA/NOVEREN put into operation a new and state-of-the-art CHP plant...
with a high-energy efficiency and effective flue gas treatment. The CHP plant in Roskilde can now supply electricity to about 65,000 households and heating to about 40,000 households. This saves burning large quantities of oil, coal and/or gas. In so doing the plant is a considerable contributor to CO2-neutral energy production.

Therefore our core activity is therefore an immediate continuation of the symbiosis mindset where resources are provided, and where waste streams can be shared and exploited for the mutual benefit of both the economy and the environment.
SUPPLY CHAIN SECURITY AND MINIMISATION OF COSTS

SØREN CARLSEN
Senior Director
Novozymes A/S

Energy and water costs and the treatment of waste water make up a substantial part of our production overheads. There is no doubt that Novozymes with its involvement in the Kalundborg Symbiosis has found solutions that help us keep expenses at a minimum for water, steam and liquid waste treatment. As Novozymes’ manufacturing plants are very large, supply chain security is a parameter that means a lot to us for many years to come.

Local co-operation plays a vital role here. Based on previous co-operation and the mutual obligation that the Kalundborg Symbiosis embodies, we foresee that solutions will also be found in the future that can ensure our possibilities of having a production that is both attractive from the point of view of the environment and an operating economy. The co-operation that has been going on for many years now between industry and the municipality makes it natural that major projects involving energy consumption and waste management are organised as a joint effort.
Arne Remmen is professor and Deputy Head of Department of Development and Planning at Aalborg University. He began his academic career at Aalborg University in 1980, and he holds a PhD in Constructive Technology Assessment, an MA in Social Science and a BA in Psychology.

Arne Remmen’s primary research areas include Environmental Politics and Management and Organizational studies. His professional interests are primarily in the fields of technological innovation, implementation and public regulation as well as conflict and learning processes regarding technological change. His recent research focuses on circular economy and resource efficiency in projects relating to Designing out Waste, Resource-efficient Production and Products, Circular Business Models etc. He is one of the initiators behind the Network for Sustainable Business Development that also contributes to the implementation of Industrial Symbioses in Northern Jutland.
The Industrial Symbiosis in Kalundborg has enjoyed international fame for the past 25 years, but at the same time it is also a well-kept secret in Denmark. How can this be?

In 1990, we set up a research group in Cleaner Technology at Aalborg University that became involved in several projects concerning pollution prevention and implementation of clean technology in Danish enterprises. Working in this field, we were aware that something interesting had been going on in Kalundborg, where they were utilising residual by-products generated from one industrial process for re-use as a raw material in another industrial process. Really smart, no doubt! On the other hand, many Danish municipalities also had combined heat and power plants, and other municipalities such as Kolding were using hot water from the power plant in aqua-culture, in this case fish farming, as an employment project. Was Kalundborg really doing something more remarkable than the others?

According to one of the early pioneers of the Society of Industrial Ecology, John Ehrenfeld, there was no doubt; Kalundborg Symbiosis was a unique prototype for how to make Industrial Ecology work in practice. I met Ehrenfeld in Boston in the summer of 1993, and he was surprised that his visitor knew even less than himself about Kalundborg. So I spent part of my sabbatical in USA “doing my homework”, reading about the world famous Industrial Symbiosis in Kalundborg.
Back in Denmark in 1994, the new focus was environmental management systems, and several companies were busy implementing ISO 14001. Cleaner production was now regarded as being much more than a technical issue, it was also a matter of management commitment, employee participation and “picking the low-hanging fruit” through good house-keeping and by changing old routines and habits. However, only a few had their attention focused on Kalundborg.

The third “European Roundtable on Cleaner Production” in 1996 was instrumental in making the Symbiosis world famous – even in Denmark! This was my first visit to Kalundborg Symbiosis and it was the first and last time in the history of the Roundtable that a city was too small to host a conference. However, Kalundborg rented a ferry so the hotel capacity was increased, allowing most participants to be accommodated in cabins on the boat. In the report issued by the Danish Ministry of Environment shortly after the conference, one can read:

"In Kalundborg Symbiosis, four enterprises in an industrial area in Kalundborg exchange and utilise each other’s waste streams whereby pollution is avoided and resources saved. The symbiosis is based on contracts between the enterprises involved. It is workable, because of the short distance between the companies both in terms of meters and mentality. All of the managers know one another. The cooperation is built on trust and the fact that the companies are not competing with each other" (Ministry of Environment, 1996).

This quote captures the essentials. Kalundborg Symbiosis is all about synergy, when 1+1 becomes greater than 2. Most scholars have been impressed by the idea of waste equals food, as a common saying is today. Connecting the waste material flows, exploiting residual products as a local resource, the system thinking and reduction of the impact on the environment are immediately apparent and provide the physical foundation for the Industrial Symbiosis.
However, the really unique part about Kalundborg is succinctly what one of the initiators Jørgen Christensen coined in an one-liner already back in 1994: “Systems make it possible, but people make it happen”. This captures the core essence of the symbiosis idea.

Kalundborg Industrial Symbiosis is a “local produce” that has grown organically from the bottom-up within a local community as a result of the trust and credibility among the partners engaged, who work together in close proximity both in “metres and mentality”. The social capital invested by the people engaged combined with communication is the main explanation for its long durability and has proved to be a sustainable pathway to an Industrial Symbiosis.

Due to the international success of Kalundborg Symbiosis, one aspect of the Danish government program on “Green transition” is now focussing on Industrial Symbiosis, and allows industries all over Denmark the possibility to receive funding for exploring potential for Industrial Symbioses.

Kalundborg Symbiosis is still going strong and is looking more dynamic and exciting than ever. The challenge now is to move beyond the traditional limitations of Industrial Ecology, and demonstrate to the world and the rest of Denmark that an Industrial Symbiosis can reduce waste and at the same time be based on 100% renewable energy. Kalundborg Symbiosis is an exceptional role model and created the fertile ground for hundreds of new symbioses to flourish all over Denmark.

Kalundborg Symbiosis has played a vital role in promoting local and regional development thereby creating new “green” jobs that provide further incentives to extend the social capital to partnerships between the public and private sector as well as citizens and research institutions actively involved in similar projects. Partnerships among people, public, private, and professionals (4P) can further expand the innovation potentials in an Industrial Symbiosis 2.0 that focuses on making a 1:1 learning
laboratory for the circular economy in Denmark – a new role model: Kalundborg Industrial Symbiosis – Smart and Sustainable (KISSS).

Most Danish fairy tales have a happy-ending. Kalundborg Industrial Symbiosis reminds me in many ways of the fairy tale by Hans Christian Andersen about Clumsy Hans, who won the heart of the princess and impressed her with his playful turning waste into resources using things he happened to find along the road. That’s how Clumsy Hans won the princess and the whole kingdom and lived happily ever after.
EFFICIENT AND SUSTAINABLE PRODUCTION

MOGENS NIELSEN
Regional Managing director
Saint-Gobain Gyproc, Nordic & Baltic countries

The Industrial Symbiosis in Kalundborg has been of great importance to Saint-Gobain Gyproc for many years.

Since the beginning of the nineties we have purchased large quantities of gypsum from Dong Energy. This gypsum is known as synthetic gypsum and is a by-product of the power station’s electricity production. Synthetic gypsum has replaced for us natural gypsum which we otherwise would have used in our production.

The most obvious advantage is that synthetic gypsum is produced locally while natural gypsum comes from gypsum quarries and must be imported. Using synthetic gypsum means far better and more environmentally friendly utilisation of our raw materials, and at the same time it makes economic sense that the raw materials are available locally.

Not only that; the Industrial Symbiosis and our use of locally produced synthetic gypsum have furthered the understanding of gypsum board as an extremely sustainable product.