A Natural Fit

It started with a deal for flare gas and grew into an industrial ecosystem: One plant uses what another casts off.

By R.P. Siegel

There's amazing symmetry in natural processes. Breathe deep and think of oxygen. It's a waste product of photosynthesis.

On the other hand, one of the key ingredients for that process is carbon dioxide, a byproduct we create by the metabolism of food. Much of our nourishment comes from the oxidation of sugars developed by photosynthesis. It's a simple example of symbiosis: What one organism leaves, another uses.

This kind of cooperation can also be applied by industry. Gypsum captured from the flue of a coal-fired power plant can become the raw material of a factory making drywall sheets. The effluent cooling water from the power plant can become the preheated boiler feed water for a refinery. The sulfur extracted by the refinery can be sold to a manufacturer of sulfuric acid.

That is the kind of symbiosis that characterizes a unique industrial park in the town of Kalundborg, Denmark. Known as the Kalundborg Symbiosis, it is a community of eight companies that cooperate with each other to everyone's benefit, because one company's waste becomes another's feedstock.

The relationship increases efficiency and reduces waste-handling. The result is an industrial cluster that has reduced its environmental footprint and improved the bottom line of each of the participating companies.

The Kalundborg Symbiosis comprises four major industrial companies, the local electric and water utilities, a wastewater treatment plant, and a solid waste facility. They form a network in which materials and energy flows are cooperatively exchanged. In these exchanges, byproducts of one operation become raw materials or inputs of another.

According to materials provided by the Symbiosis Center Denmark, a newly formed, state-sponsored outreach and development agency, the results add up to annual reductions of 275,000 tons of CO_2 and three million cubic meters of water, based on data collected in 2008.

The Kalundborg Symbiosis recently celebrated its 40th anniversary. As the symbiosis has grown, both in complexity and effectiveness, it has developed numerous ways in which businesses can reduce their impact on the environment without sacrificing competitiveness.

Mette Skovbjerg, who heads the Symbiosis Center, says it began with a scarcity of resources, particularly groundwater, in Kalundborg, a small city situated at the head of a fjord on the west coast of Zealand. The city, with roots reaching back as far as 1170, is part of a larger municipality of the same name that covers almost 600 square kilometers and has a total population of about 50,000.

In 1959, the Asnæs Power Station, a large coal-fired plant, was constructed to serve the community. Two years later, the Tidewater Oil Co. built a refinery. Because of the shortage of ground water in the area, the refinery owners negotiated an agreement with the Kalundborg municipality to construct a pipeline to bring fresh water from Lake Tissø, about 10 km southeast.

In 1972, Gyproc constructed a drywall manufacturing plant. The company needed a lot of energy for drying the sheets and negotiated an arrangement with the refinery to utilize excess gas that was being flared off. Thus, the symbiosis was born.

Among the companies located in Kalundborg today, the biggest is Novo Nordisk, the world's largest supplier of insulin. The company, which was founded in 1923, located in Kalundborg in 1969, back in the days when insulin was still extracted

The Kalundborg Symbiosis

An industrial park in the Danish municipality of Kalundborg (see aerial photo below) links a refinery, a power plant, and several factories so they can use each other's products and wastes.

Energy

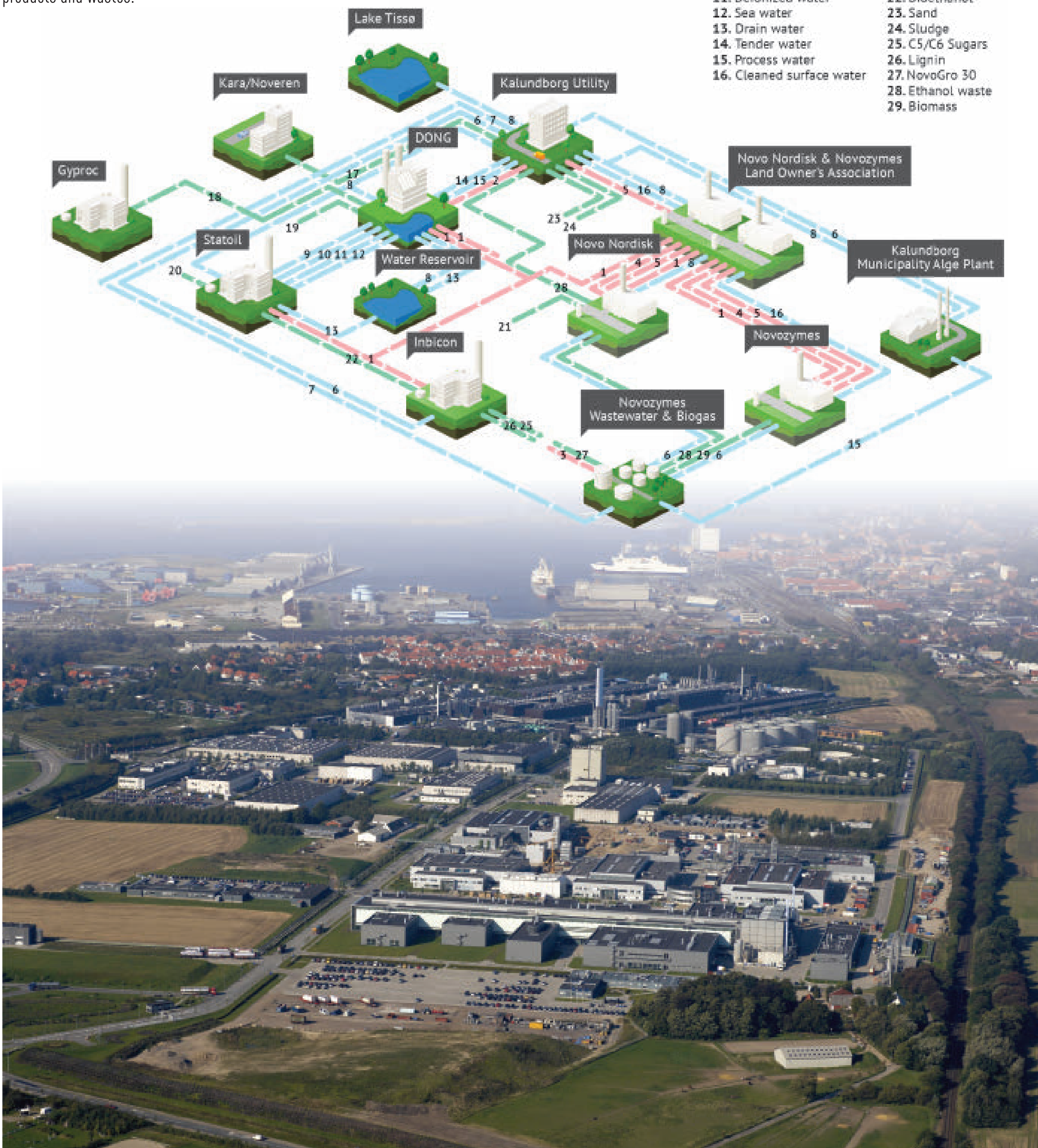
1. Steam
2. District heating
3. Power to grid
4. Warm condensate
5. District heating

Water

6. Waste water
7. Cleaned waste water
8. Surface water
9. Technical water
10. Used cooling water
11. Deionized water
12. Sea water
13. Drain water
14. Tender water
15. Process water
16. Cleaned surface water

Materials

17. Waste
18. Gypsum
19. Fly ash
20. Sulphur
21. Slurry
22. Bioethanol
23. Sand
24. Sludge
25. C5/C6 Sugars
26. Lignin
27. NovoGro 30
28. Ethanol waste
29. Biomass



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from pig pancreases. Today, the active ingredient is grown in yeast in an enormous one-million-square-meter facility, which produces roughly half of the world’s insulin. The insulin is grown in a fermentation process. It is harvested, purified, dried, and then frozen. The fermentation process produces heat which is captured and reused internally.

Back in the 1970s, Novo Nordisk began providing agricultural sludge from this yeast production line to neighboring farmers. Around the same time, the operators of the power plant began providing fly ash to cement producers in the north.

Steam was the next development. At first, the power plant provided steam for district heating. Then, Novo Nordisk and Statoil collaborated to build a steam pipeline connecting the power plant to their facilities, allowing them both to shut down far less efficient boilers.

By this time, engineers in Kalundborg began to notice more opportunities as the efficiency benefits of resource sharing were becoming part of their respective business models. The Statoil refinery added a pipeline to carry warm cooling water effluent to the power plant for use as raw boiler feed water, improving the efficiency of the same boiler that was providing steam.

CIRCULAR THINKING

Take a walk through the Kalundborg Symbiosis today, and you would see something that looks a lot like any other industrial complex. The one thing that would likely stand out would be the network of pipes running at ground level and sometimes rising to cross streets, connecting the buildings with one another. The lines, which transport gas, water, steam, waste slurries, and other effluents, suggest a single interconnected organism in which each building plays the role of an internal organ.

Over the years further opportunities were recognized and implemented. A Statoil sulfur recovery plant sells sulfur to a sulfuric acid manufacturer. Biologically treated refinery effluent is used in power plant for cleaning and for fly ash stabilization.

Warm cooling water from the coal power plant runs to a fish farm that produces turbot and trout. Waste heat from the power plant is used for a bio-refinery that has produced 5.4 million liters of ethanol from waste materials generated around the site and by local farmers.

Agricultural fertilizer is recovered from the power plant’s sulfur and nitrogen scrubbers. Calcium sulfate (gypsum) from its flue gas scrubber is a raw material used by Gyproc in the production of drywall. About 150,000 tons of gypsum are recycled each year.

Many of these symbiotic actions can be replicated elsewhere. But clearly having the facilities co-located, allowing material to be piped rather than shipped, makes symbiosis particularly attractive.

In 2013, Novo Nordisk and Novozymes, another Kalundborg partner company specializing in the production of enzymes, collaborated on the construction of an on-site biogas reactor that extracts methane gas from wastewater. The 35-meter-tall reactor feeds a gas turbine on site that generates 47,000 megawatt-hours per year—enough electricity for 12,000 homes—and reduces carbon emissions by an additional 21,000 tons.

“The Symbiosis came about as the result of a spirit of collaboration,” said Michael Hallgren, senior vice president at Novo Nordisk Kalundborg, “and a response to the question: Is it possible that a waste product of one company could actually be a raw material for another?”

This idea of using waste as a raw material is now known as the circular economy. Kalundborg is held up as an example of this concept by organizations that seek to promote it, such as the Ellen MacArthur Foundation and the Nudge Sustainability Hub.

The Kalundborg partner companies have created their own circular economy, Hallgren said, and “have incorporated it into their DNA.”

Hallgren pointed to the example of Novo Nordisk, a long-time leader in sustainability. Back in 2004, the company could see that its carbon emissions and water consumption were increasing proportionally with its revenues.

That raised a question: Could the company grow without

The green pipe stretching over the road in the Kalundborg complex carries steam from one facility, which considers it an unneeded by-product, to another that uses it for production.

the undesirable consequences? "That was the goal," Hallgren said, "but nobody knew how to do it."

Novo Nordisk initiated a partnership with Dong Energy, the operator of the Asnæs Power Station, to see what could be done.

Dong wanted to build windmills. According to Hallgren, Novo Nordisk told the power company, "You are the experts in energy. If you can support us in coming up with a lot of ideas—take a look at our production process and see where you can find savings—any money that we actually save we will reinvest in windmills."

Everyone got what they wanted. "They built a huge windmill park on the west coast of Jutland, and we agreed to buy all the energy coming out of there," Hallgren said. "Today all the power for our Danish production site is coming from windmills. We also looked at our own production, and the yeast strains to see if we could produce more per liter, because that would also reduce our use of resources including CO_2, power, and water."

The effort was successful. "We have decoupled our resource consumption from our sales," Hallgren said. "First of all, sales increased while CO_2 emissions remained flat. Then we made a commitment in 2006 to reduce CO_2 emissions to 10 percent below what we emitted in 2004. Emissions remained flat while sales grew until 2007 when the emissions began to decline." As sales continue to increase, the company must work ever harder to find ways to reduce emissions.

The project is by its very nature dynamic, and changes in one plant's operations ripple out to others in the Symbiosis. For instance, the 1,057 MW coal plant, which played such a key role in the growth of the symbiosis, is being phased out, giving way to wind power. As a result, Gyproc will need a new source of gypsum to replace the calcium sulfate it currently receives from the coal plant. Several facilities will need a new source of steam, and the members of the Symbiosis team are working on a project to build a smaller steam unit that will burn wood and produce power for the community.

Mette Skovbjerg, head the Symbiosis Center, pointed to municipality-initiated demonstration project involving the use of microalgae. Novozymes is taking off wastewater and using the algae to clean it. That process will also create byproducts which could either be used to produce more bioenergy or possibly more high-value oils.

This, Skovbjerg said, "is part of version 2.0 of the symbiosis where you don't just take a residual and turn it into a resource, but you are now creating high-value products from something that was essentially a waste."

As the thinking evolves, so does the value realized.

A FUTURE FOR WASTE

While the Symbiosis has more or less run itself without anyone promoting it for most of its existence, recent recognition by outsiders has led to more efforts to attract more businesses and to promote what has been done here. This includes the formation of Symbiosis Center Denmark and a national task force that conducted a feasibility study to explore additional opportunities for the Symbiosis concept beyond Kalundborg.

The task force found that a shift to a circular economy in Denmark could, by 2035, increase the GDP by up to 1.4 percent annually, increase exports by 3 to 6 percent, increase employment by up to 13,000, reduce Denmark's carbon footprint by 3 to 7 percent, and reduce the use of resources by as much as 50 percent.

The study looked primarily at manufacturing, but it mentioned that other industries, such as food and beverage processing and construction, could also benefit from symbiotic arrangements.

The advantages include greater productivity, lower costs, and reduced waste. Even so, getting companies to buy into the idea can take some finesse.

"What we do is not to persuade," Skovbjerg said, "but to explain to companies that this is not something that is going to make them more dependent, as much as it will help them optimize their use of resources, improve their bottom-line figures and their competitiveness."

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