Appendix D

Agriculture Symbiosis International Profiles

1. Overview

As a component of our targeted research to inform this report, we conducted a global scan of agriculture symbiosis examples and produced these short descriptions.

This appendix is intended to: 1) demonstrate the great variety of agriculturally-relevant symbiosis opportunities that have been realized across a range of geographic, political, and economic conditions around the world; 2) underline the potential for modest small-scale partnerships to evolve into major multi-stakeholder operations with large, locally-important economic footprints; and 3) highlight the variety of conditions under which these associations began and some of the impetus for how they grew into what they are today.

Among the following examples, we are sharing both true multi-party industrial symbiosis examples, as well as some key examples of in-house circularity that we found especially compelling. As described in our report, optimizing the use and reuse of energy, water and organic materials within a business's facilities and across its operations is often an important first step to developing more complex symbiotic associations.

This is just a sampling of global agriculture symbiosis examples and is by no means exhaustive. The majority of case studies we investigated were from Europe, with a few excellent examples also coming from Asia.

1.1 Solrød Biogas - Denmark

This project emerged from an effort to utilize decaying seaweed that washed up on local beaches, and was creating a nuisance odor for residents and tourists. The solution identified by stakeholders was to generate biogas using the seaweed as a feedstock. The successful experiment prompted further consideration of other existing resources. Today Solrød Biogas, owned in part by the municipality of Solrød, utilizes over 190,000 tons of biomass feedstocks per year from local industries, from several distinct waste streams. The biomass is used primarily for the production of heat and electricity to replace fossil fuel inputs, but it also generates other key products. Local 'waste' resources are key to their success, as well as national policies, grants, subsidies, and academic and research engagement.

In addition to seaweed, major bio-feedstocks include lemon-derived pectin and carrageenan (a biotech waste), as well as general organic pulp, and manure from local farmers. The biogas is produced through a cascading system, which utilizes 55% more of the raw materials than would otherwise be used. The contained nature of the process also reduces the methane emissions that would otherwise occur. This results in a CO_2-neutral biogas which can replace fossil fuel energy when it is used for vehicles, sold to the grid, or used for combined heat and power (CHP). CHP uses an input like biogas to produce both electricity and useful heat, which in this case is used to heat the local district heating system owned by several municipalities. The biomass from the anaerobic digesters, as well as condensate from the gas cleaning process, are used to make a sustainably produced fertilizer for farmers to use. This reduces the need for chemical fertilizers, which results in less leaching of Phosphorous and Nitrogen into the aquatic environment. [1]

1.2 Kalundborg Symbiosis – Denmark

Kalundborg Symbiosis is a resource partnership between 16 entities, including both private companies and public operators. In a city of just 17,000 people, this project produces $28 million in yearly economic value, and saves 600,000 tons of CO_2 emissions. It began in the early 1970's as a collaboration when Statoil refinery, a petroleum producer, agreed to supply their excess gas to Gyproc, a gypsum producer, who used it to dry plasterboards in their ovens.

Because of the significant economic, cultural, and environmental benefits resulting from symbiosis the group has grown organically through a cooperative process over the 5 decades since their inception. Today the local municipality serves as a multi-utility providing distributed drinking water, process water, cooling water, wastewater treatment, water system management, and district heating. Ultimately, 20 different resources are exchanged between the participants, helping make Kalundborg one of the most mature and well-known examples of industrial symbiosis in the world. Excess gas is used for energy, biological sludge is delivered to farms, and fly ash from the power plant is supplied to cement manufactures. Half of one facility's energy came from within the network, and another was able to reduce its oil consumption costs by 95%. Within the next decade, they hope to use all resources and achieve zero waste. [2]-[5]

1.3 Biowert - Germany

This Swedish-German company began operating their first grass refinery in 2007. Their process converts locally grown meadow grass from permanent pastureland into a variety of products such as plastics, flavorings, and fertilizers, all of which are either recyclable or biodegradable. The generated plastics are more environmentally friendly than their petrol-based equivalents. The grass inputs are all locally produced and the company strives to use 100% recycled materials as part of their 'cradle to cradle' ethos.

Heat and water are cycled within the facility. Byproducts include a grass slurry, which can be fed into a biorefinery along with other inputs such as food waste. The gas produced is sent to a combined heat and power facility which covers the heat and energy needs of the entire facility, with excess being sent to the grid. Digestate from the biogas is turned into a fertilizer which can be applied to the fields of meadow grass which serve as their supply, and wastewater is reused for pretreatment of the grass. [6]-[9]

1.4 Sotenäs Symbiosis – Sweden

Before symbiosis, industry in Sotenäs was growing beyond what the region could handle. Seafood processors were prohibited from releasing any more process water into the local environment, and much of the waste was shipped to other regions in Sweden, as well as Norway and Denmark. To address this problem, local entrepreneurs and municipalities developed a new sustainable development strategy. As a result, a new biogas facility was built along with a wastewater purification plant. This allowed industrial activity to thrive while keeping emissions and waste from growing out of hand. The strategy was aided by an ongoing collaboration between Linköping University and the Symbiosis Centre, a municipal office which facilitates operations in Sotenäs.

Today many industrial sites and processing facilities exist in close proximity, allowing for easier exchanges of resources. These resources include organic waste and upcycled ocean waste (e.g. plastics, nets, and other debris) which are processed and fed into a biogas and wastewater facility. Other inputs are received from factories and fish facilities, which are exchanged for energy, water, and fertilizers as outputs. The biogas facility, for example, gives energy to a land-based fish farm, Smögenlax, which in turn provides sludge which can be used to make biogas. A Swedish Algae Farm operation then uses the effluent from the fish farm to cultivate its algae and produce specialized chemicals. A host of other connections all contribute to a community-driven attempt to create a circular economy. Research suggests that symbiosis will continue to boost the GDP of the area, increase jobs, and strengthen regional identity. [10]-[12]

1.5 Swedish Algae Factory

Located in Gothenburg, Sweden, the Swedish Algae Factory cultivates diatom algae to extract their silica shells. The algae is grown in a large greenhouse, and the materials extracted in a nearby facility. The resulting product, Algica, can be used as an environmentally friendly component of personal care products or as an efficiency-enhancing component of solar panels.

The algae is continuously collected by a self-propelled harvester. Nutrient-rich water that would otherwise have to be cleaned is taken from nearby food industry. The water is cycled through the algae system which removes nitrogen and phosphorous, and is then clean enough to send back to the food industry. This reduces wastewater and avoids effects such as eutrophication from runoff. Any waste biomass from production is used to create biofuel, converted to fertilizer, or used as livestock feed.

They have also partnered with a land-based fish farm, Smögenlax. Located in Sotenäs, Sweden, wastewater from the fish is cycled through the algae growing area to remove nitrogen and phosphorous, which allows it to be cycled back into the ponds. Some of the algae biomass is also used as feed for the fish. This operation shares connections with the greater symbiosis network in Sotenäs. [11], [13]-[15]

1.6 British Sugar, Wissington Factory – United Kingdom

British Sugar's Wissington factory was established in 1925. Today it is the largest beet sugar operation in the UK, and one of the largest in Europe, partnering with several hundred farmers who supply them with sugar beets. An initial focus on trying to use every available byproduct from sugar beet processing has led to the formation of many joint ventures. At least twelve coproducts have been identified, including betaine (used in cosmetics), bioethanol, CO_2, and electricity. Development of these additional products has led to increased sugar revenue, and greatly increased co-product revenue.

Methane from an anaerobic digester is used as fuel at a CHP plant, which in turn sends CO_2 to a horticulture complex. In addition, the CHP plant provides energy for the first bioethanol plant in the UK, established in 2007, which British Sugar established at Wissington. They also plan to introduce a spirulina plant to produce algae as feed for livestock. The plant would utilize excess boiler gas in the process. The company is continuously analyzing new ways to utilize any flows that may currently go to waste. [16]-[19]

1.7 Nanjangud Industrial Area – India

Nanjangud is an industrial area in India with 45 facilities, surrounded by a large agricultural community. The main focus is production of sugar and coffee. Around 900,000 tons of waste residues are produced annually by the partnering industries, and 99.5% of these residuals are being reused or recycled at least once within or across companies.

91% of the residuals are biomass. Most of that is bagasse, a fibrous sugar cane byproduct with high energy and low nutritional content. The bagasse is combusted within the industrial area to meet its 4 MW of power needs. The remaining 36 MW is sent to the grid. Boiler and fly ash are generated as a byproduct, which can serve as soil amendments for local farmers. The rest of the biomass residuals are food wastes that either directly or with processing, can generate fertilizers for local agriculture. In one example of resource exchange, an oil extraction facility provides boiler fuel to a food processing facility, which in turn sends spent coffee as feedstock back to the oil extractor.

90% of the reused products go to facilities within 20km of the industrial area, with two thirds of that going to direct reuse. Waste that was already similar to existing commodities tends to be sold to recyclers, while less standard waste like food residues are used within the industrial area. This arrangement came about organically, with no advance planning, perhaps due to a high degree of trust and shared norms among the partners. Ultimately the synergies that have been identified correlate with increased product sales and market success. The industry partners are actively seeking ways they can put to use the ash that currently makes up the last 0.5% of residuals that are not yet recycled. [20], [21]

1.8 GreenLab Skive – Denmark

A green, circular energy park that generates onsite renewable energy for participating companies. A variety of renewables, including solar and offshore-wind are currently producing power, and there are plans to also make use of green hydrogen. The park employs a system called SymbiosisNet which monitors data and energy usage, while supporting efficient exchange. There is a strong research aspect to the park which encourages testing of new methods and technologies in partnership with Danish universities.

GreenLab utilizes innovative electric power distribution methods, such as sector coupling which stores electricity in an intermediary industry. They are one of the first Power-to-X facilities, meaning they convert clean energy into a transportable form for use in transportation and industry. A planned large-scale green hydrogen production plant developed by Green Hydrogen Systems will facilitate these efforts.

Organic waste from local farms is used in the production of jet fuel and food proteins, while manure serves as a feedstock for their biogas facility. The residual fibers from biogas production feed into a neighboring facility which produces biochar and pyrolysis-gas. The CO_2 byproduct from the biogas facility will be used with the green hydrogen to produce bio-methanol, while any extra green hydrogen may result in boosts to biogas production. One plant uses invasive starfish to produce organic proteins for animal feed, while another will upcycle soiled plastic to create new products.[22]-[25]

1.9 Dutch Greenhouse Agriculture

Dutch greenhouses are renowned for their quality and efficiency. Though the Netherlands is small geographically, its vast array of greenhouses covering 80% of their cultivated land have helped it to become the second largest exporter of agricultural products in the world (Washington Post, Nov 21, 2022). This is in part due to their use of a "precision farming" system that allows detailed analysis and precise application of water and other inputs. These, among other innovations such as improvements to greenhouse heat retention, allow greater production and more efficient use of resources. This is aided by ongoing research, like that being done by the Dutch food research hub Wageningen University and Research.

The greenhouse industry does face some challenges, such as the high energy demanded by plant lights which contribute to light pollution, and the potential pollution of surrounding surface waters. However, there are some examples of how these issues might be addressed. The Duijvestijn Tomatoes company for example, uses geothermal energy and a hydroponics system. The roots are kept in rockwool, which allows even greater water efficiency. The closed-circuit aspect of their water system means that the plants receive only as much water as they need, so that there is no runoff. This means there's no avenue for any fertilizers to escape and pollute the surroundings. They also pump waste CO_2 from a local Shell oil refinery to help feed their plants and reduce emissions.[26]-[29]

1.10 Guitang Group – China

The Guitang Group began as a cane sugar business in the Guangxi Zhuang Autonomous Region, an area of China that accounts for 40% of the country's sugar production. The group also uses sugar cane residue, known as bagasse, as an input at a large paper production facility. Efforts to use bagasse and other wastes have led to several new production lines including alcohol, pulp, toilet paper, calcium carbonate, cement, and power generation. The company has continually seen new opportunities for symbiosis over their four decades in operation, resulting in new earnings while generating less pollution and emissions.

In addition to bagasse, other fiber sources are used such as locally produced rice and bamboo waste. Ash and other organic wastes from sugar production can be used in cement production, alcohol byproducts are used to create fertilizer, and the calcium carbonate plant utilizes wastewater from paper mills, among other resource exchanges. Organic wastes are also sent back as soil amendments and organic fertilizer to the fields that supply sugar canes. These are provided by the Guitang Group at no cost to the local farmers whose products are processed by the Group. This is done to encourage use of organic practices which can ultimately raise the valuation of the Guitang Groups products. More facilities and connections are planned for future development.

A challenge the group faces is that demand for their waste-derived products tends to exceed the available local feedstock supply . As a result the group has worked to acquire feedstocks from competitors. That effort has succeeded in part due to government mandates requiring smaller producers to send their byproducts to the Guitang Group. [30]-[32]

1.11 Volta Greentech – Sweden

Volta Greentech is a land-based algae producer located in Sweden. The algae produced is used as feed for local cattle, which substantially reduces greenhouses gases produced by the cattle. This is possible because the algae contains a compound known as bromoform, which in cows inhibits the digestive enzyme that forms methane. Based on the available data, roughly 60 grams of seaweed feed per cow each day, is enough to reduce methane emissions by roughly 80%. The technology is licensed from the Australia agency CSIRO.

At Volta Greentech, electricity is fully provided by renewable sources, and waste heat from nearby industries is utilized. The seawater used for cultivating the seaweed is pumped in and recirculated, saving on water usage. Plans are in motion to create a symbiotic relationship with the plant-based food company Mycorena, using the CO_2 waste produced through fungi fermentation to help bolster algae growth.[33]-[37]

1.12 100% Fish Project – Iceland

Run by the Iceland Ocean Cluster, the goal of this project is to maximize efficient use of fish in ways that minimize waste, support new business opportunities and employment, and increase the value of every fish. Compared to the rest of Europe and North America where roughly 50% of the average cod's weight is wasted, industry in Iceland has reached roughly 80% utilization of white fish.

Success in this regard has been primarily due to research and development in the areas of processing and handling. New parts have been utilized such as bones and dried heads, and companies that specialize in using fishery by-products have grown and developed innovative processes. New products have ranged from cosmetics to proteins to pharmaceuticals.

In Iceland the government offers general supports for green business and innovation, which has helped circular practices to flourish. There are also private sector initiatives, such as CleanTech Iceland and Hafið, which both focus on sustainable tech solutions including in the fishing industry. The Svartsengi Resource Park also engages industrial symbiosis and is entirely driven by private entities like HS Orka, with activities ranging from geothermal power to fish drying to R&D.[38-40]

References

[1] "Solrød Biogas - Towards a Circular Economy," 2015. Available: https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/03/Solrod_Biogas_Case_Story_web.pdf

[2] CEF "Kalundborg — The World's First Fully Functional Industrial Symbiosis," CEF, Aug. 29, 2016. https://corporateecoforum.com/kalundborg-worlds-first-fully-functional-industrial-symbiosis/

[3] "Kalundborg industrial symbiosis," wwf.panda.org. https://wwf.panda.org/wwf_news/?204431/Kalundborg-industrial-symbiosis

[4] "Kalundborg Symbiosis: six decades of a circular approach to production | European Circular Economy Stakeholder Platform," circulareconomy.europa.eu. https://circulareconomy.europa.eu/platform/en/good-practices/kalundborg-symbiosis-six-decades-circular-approach-production

[5] "Kalundborg Symbiosis - The world's leading industrial symbiosis," Kalundborg Symbiosis. https://www.symbiosis.dk/en/

[6] "BIOWERT GRASS BIOREFINERY BIOBASED PLASTICS, GERMANY IEA Bioenergy Task 37 BIOGAS IN SOCIETY A Case Story." Available: https://www.ieabioenergy.com/wp-content/uploads/2019/07/IEA_grass-refinery_end.pdf

[7] Biowert Industries, "BIOWERT - bio based industry," biowert.com. https://biowert.com/company/cradletocradle

[8] N. Hatvani, M. Van Den Oever, K. Mateffy, and A. Koos, "Bio-based Business Models: specific and general learnings from recent good practice cases in different business sectors," 2022, doi: https://doi.org/10.36253/bae-10820.

[9] Pollution Solutions, "Green Solutions from Green Company," Pollution Solutions Online. https://www.pollutionsolutions-online.com/news/consultancy-services/19/biowert-industrie-gmbh/green-solutions-from-green-company/20959

[10] "How Sweden's most sustainable industrial cluster was created," liu.se. https://liu.se/en/news-item/sa-skapades-sveriges-mest-hallbara-industrikluster

[11] Smogenlax "SCH Illustrations," Smogenlax.se. https://smogenlax.se/wp-content/uploads/2021/03/SCH_illustrations_eng.pdf (accessed Jun. 07, 2023).

[12] S. Harris, "Socio-economic assessment of the Sotenäs Industrial Symbiosis Network," RISE, Jan. 2018. https://www.ri.se/sites/default/files/2023-04/Bilaga%203%20Socio-economic%20assessment%20Soten%C3%A4s%20Industrial%20symbiosis.pdf (accessed Jun. 07, 2023).

[13] M. Martin and S. Harris, "Prospecting the sustainability implications of an emerging industrial symbiosis network," Resources, Conservation and Recycling, vol. 138, pp. 246–256, Nov. 2018, doi: https://doi.org/10.1016/j.resconrec.2018.07.026.

https://smogenlax.se/wp-content/uploads/2021/03/SCH_illustrations_eng.pdf[14]"Swedish Algae Factory," swedishalgaefactory.com. https://www.swedishalgaefactory.com/

[15] "The Swedish Algae Factory - Nordregio," archive.nordregio.se. https://archive.nordregio.se/en/Publications/Publications-2016/GREEN-GROWTH-IN-NORDIC-REGIONS-50-ways-to-make-/Blue-growth-/The-Swedish-Algae-Factory-/index.html

[16] "Britain opens first bioethanol plant," Reuters, Nov. 22, 2007. Available: https://www.reuters.com/article/environment-biofuels-britain-dc-idUSL224214720071122

[17] J. Bates "British Sugar plans could lead to world-first protein product plant," Lynn News, Aug. 23, 2022. https://www.lynnnews.co.uk/news/british-sugar-plans-could-lead-to-world-first-protein-produc-9270355/

[18] "Make the most of these beets: increasing diversity and building resilience in the sugar industry," European Circular Economy Stakeholder Platform, Apr. 11, 2018. https://circulareconomy.europa.eu/platform/en/good-practices/make-most-these-beets-increasing-diversity-and-building-resilience-sugar-industry

[19] S. W. Short, C. Y. Barlow, and M. Chertow, "From Refining Sugar to Growing Tomatoes Industrial Ecology and Business Model Evolution," Jan. 2014.

[20] A. Bain, M. Shenoy, W. Ashton, and M. Chertow, "Industrial symbiosis and waste recovery in an Indian industrial area," Resources, Conservation and Recycling, vol. 54, no. 12, pp. 1278–1287, Oct. 2010, doi: https://doi.org/10.1016/j.resconrec.2010.04.007.

[21] W. S. Ashton and A. C. Bain, "Assessing the 'Short Mental Distance' in Eco-Industrial Networks," Journal of Industrial Ecology, vol. 16, no. 1, pp. 70–82, Feb. 2012, doi: https://doi.org/10.1111/j.1530-9290.2011.00453.x.

[22] "About," GreenLab. https://www.greenlab.dk/about/

[23] "Danish town seeks green transition redemption – DW – 07/18/2022," dw.com. https://www.dw.com/en/danish-town-embraces-circular-economy-in-bid-to-go-green/a-62478930

[24] "Greenhyscale | Greenhyscale," Greenhyscale.eu, 2023. https://greenhyscale.eu/

[25] "GreenLab," State of Green. https://stateofgreen.com/en/solution-providers/greenlab/

[26] A. Peters, "These eerily beautiful glowing buildings are the Netherlands' massive network of greenhouses," Fastcompany.com, Mar. 13, 2020. https://www.fastcompany.com/90476025/these-eerily-beautiful-glowing-buildings-are-the-netherlands-massive-network-of-greenhouses (accessed Jun. 07, 2023).

[27] D. Welle (www.dw.com), "Could high-tech Netherlands-style farming feed the world? | DW | 23.01.2019," DW.COM, Jan. 23, 2019. https://www.dw.com/en/could-high-tech-netherlands-style-farming-feed-the-world/a-47105412

[28] J. Strickler, "High-Tech Greenhouses Could Be The Future Of Agriculture," Forbes. https://www.forbes.com/sites/jordanstrickler/2020/08/28/high-tech-greenhouses-could-be-the-future-of-agriculture/?sh=211d3b96380f

[29] K. Whiting, "The Netherlands is a leader in sustainable agriculture," World Economic Forum, Nov. 27, 2019. https://www.weforum.org/agenda/2019/11/netherlands-dutch-farming-agriculture-sustainable/

[30] D. Lew, "Eco Chains in China The Guitang Group - Industrial Ecology," Dr. Darrin Lew, Sep. 28, 2021. https://www.drdarrinlew.us/industrial-ecology/ecochains-in-china-the-guitang-group.html

[31] M. Benedetti, "10 – The experience of the Guitang Group in the Guanxi province in China, leading the industrial development of the region through intra and inter firm symbiosis implementation – MAESTRI – Energy and resource management systems for improved efficiency in the process industries," May 09, 2017. https://maestri-spire.eu/experience-guitang-group-guanxi-province-china-leading-industrial-development-region-intra-inter-firm-symbiosis-implementation/

[32] Q. ZHU, E. A. LOWE, Y. WEI, and D. BARNES, "Industrial Symbiosis in China: A Case Study of the Guitang Group," Journal of Industrial Ecology, vol. 11, no. 1, pp. 31–42, Oct. 2008, doi: https://doi.org/10.1162/jiec.2007.929.

[33] J. Cornall, "Swedish startup Volta Greentech looks to build world's largest algae factory," dairyreporter.com, May 31, 2021. https://www.dairyreporter.com/Article/2021/05/31/Swedish-startup-Volta-Greentech-looks-to-build-world-s-largest-algae-factory

[34] L. Manning, "Swedish seaweed startup Volta Greentech raises $2m to grow low-emissions livestock feed," AFN, Jun. 09, 2021. https://agfundernews.com/volta-greentech-raises-2m-to-grow-livestock-seaweed-supplement

[35] Mycorena, "Mycorena and Volta Greentech Receive Vinnova Grant to Co-develop Carbon-Neutral Fermentation Scale-up Process," Mycorena. https://mycorena.com/mycotalks/mycorena-and-volta-greentech-receive-vinnova-grant-to-co-develop-carbon-neutral-fermentation-scale-up-process

[36] "Sea Forest gets funding to commercialize CSIRO seaweed feed tech," AFN, Feb. 15, 2021. https://agfundernews.com/sea-forest-cattle-seaweed-supplement-pregnancy-test-get-government-funding-in-australia

[37] Voltagreentech.com, 2023. https://www.voltagreentech.com/production/

[38] "100% Fish | Íslenski sjávarklasinn," www.sjavarklasinn.is. https://www.sjavarklasinn.is/en/100-fish/

[39] A. Berlina, N. Mikkola, & J. Teräs "Industrial Symbiosis A key driver of Green Growth in Nordic Regions?" Accessed: Jun. 17, 2023. [Online]. Available: https://www.diva-portal.org/smash/get/diva2:917631/FULLTEXT01.pdf

[40] I. H. Johnsen, A. N. Berlina, G. Lindberg, J. Teräs, L. Olsen, and N. Mikkola, "The potential of industrial symbiosis as a key driver of green growth in Nordic regions," Jan. 2015.