

Biosolutions and Power-to-X

Sector Coupling in a World Leading
Industrial Symbiosis in Greater
Copenhagen

IRISgroup

 Danish Board of
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Executive Summary

Global climate change and the demands of a growing population require new ways of producing food, energy and chemicals to be developed. Without this, we will deplete the natural resources of the planet. Biosolutions and Power-to-X (PtX) represent technology areas that have been proven to have huge potential to help humanity overcome the most serious crisis of our time.

Biosolutions refers to products and processes based on biotechnology that can be used for a variety of purposes, including increasing agricultural yields and providing alternative proteins for food. **PtX** refers to the conversion of renewable electricity into hydrogen, synthetic fuels and chemicals by means of electrolysis and synthesis.

In addition to their separate potentials and applications, Biosolutions and PtX can be combined, or “coupled”, to generate further potential advantages. These advantages are currently being explored within the Kalundborg Symbiosis in a project called “PtX Cluster Zealand”. The symbiotic environment here has existed for more than fifty years. Within it, major biotech companies and utility services are all physically connected, enabling them to share excess resources (water, energy, materials). For several reasons, integrating PtX into the symbiosis could be of considerable value. First, PtX requires access to large amounts of high-quality water, and Kalundborg Utility has many years of experience and expertise in treating and supplying surface water from the nearby Lake Tissø to local industries. Second, the main output of electrolysis is hydrogen. This hydrogen can be used directly, but it can also be synthesised into e-fuels or chemicals using biogenic carbon, which can be captured from Kalundborg’s biotech production in a process known as Carbon Capture, Utilisation and Storage (CCUS). Third, electrolysis generates oxygen and heat as surplus streams, which can be directed to the local industry and employed in district heating.

If the potentials created by the coupling of Biosolutions and PtX are to be realised in Kalundborg, access to suitably skilled employees will be vital. Over the past seven years a burgeoning educational environment has emerged with the support of a circle of local private and public actors who are focused on solving the workforce challenges in the area. Today, Kalundborg has its own educational campus. Several industry-relevant programmes are offered, including in biotechnology, and development of more programmes is under way. A research and education centre facilitating collaborative Master’s projects in which the student and local industry actors work together was also recently established.

The industrial symbiosis in Kalundborg taps into the high growth metropolitan region of Greater Copenhagen, which contains several resources of value to companies working with Biosolutions and PtX. Greater Copenhagen is governed by climate-ambitious authorities (both regionally and municipally) in East Denmark and South Sweden. It is home to flourishing life science industries and enjoys high levels of R&D investment. The region also houses several universities with leading research environments in energy technologies and basic biological sciences on both sides of Oresund. An effective infrastructure of lab and test facilities of relevance to the Biosolutions industry is under construction.

Despite a firm foundation on which Biosolutions and PtX can be expected to develop in Kalundborg, some framework conditions must be strengthened if the full potential of the technologies is to be realised. The strengthening needs to concentrate on academic-corporate collaboration, access to state-of-the-art labs and facilities and maintenance of a vibrant community for entrepreneurship with access to capital. Legislation that is fit for purpose, access to suitably qualified employees, and an infrastructure to support large-scale production will also be important.



60% of all physical inputs in the global economy could, in principle, be produced biologically.

Global potential

Towards 2030, the global achievable emission reduction potential of mature, ready to deploy Biosolutions technologies corresponds to around **8%** of current emissions globally, and this is expected to increase past 2030.



More than **20** streams of excess resources currently flow between 16 companies in Kalundborg’s industrial symbiosis.

Kalundborg

4 new educational programmes have opened over the past few years at Campus Kalundborg, and the development of 4 more programmes is under way.

To date, more than **400** students have been enrolled at Campus Kalundborg.



Greater Copenhagen houses **4** top tier universities with facilities in Biosolutions and PtX.

Greater Copenhagen

Funds equivalent to almost **4%** of GDP in Greater Copenhagen are invested in R&D.

7 facilities for bio-refinement and fermentation, covering the value chain from research to market, either already exist or are being developed in Greater Copenhagen.



Preface

This report offers insights into the “coupling” of two key technologies in the green transitioning of our economy: Biosolutions and Power-to-X (PtX). Both are of growing political interest, and both can be connected with the scientific progress that is accelerating in technological hotspots all over the world.

One such hotspot is the Danish city of Kalundborg, which has developed a world leading centre of industrial symbiosis connecting biotech companies with world-class utility services through a neat infrastructure of pipelines.

The story of Kalundborg Symbiosis is one of high-tech factories that have outperformed production sites around the world despite relatively high Danish wage levels and energy costs. The secret is sharing surplus resources.

Our report presents early thoughts on the coupling of PtX production with the biotech cluster in Kalundborg. It is important to note that the analysis given here is not based on technical calculations of input and output streams. The purpose is to convey what the current and prospective critical framework conditions are, and suggest policy directions.

Kalundborg is part of the Greater Copenhagen region, which is home to thriving life science industries and part of the world-class biotech and energy research environment in Denmark and Sweden. Therefore, when the critical framework conditions for the development of Biosolutions and PtX are analysed, the entire Greater Copenhagen region is considered.

The report is divided into four chapters. In Chapter 1, Biosolutions, PtX and their coupling potential are introduced. In Chapter 2, industrial symbiosis and the local innovation district in Kalundborg are described. Here, the infrastructural basis and other conditions for PtX in Kalundborg are also discussed. The Greater Copenhagen ecosystem is explored in Chapter 3. Finally, in Chapter 4 important conditions for the development and production of Biosolutions and PtX in Greater Copenhagen are considered, following which policy recommendations are made.

The analysis is based on desk research, and on interviews with biotech and PtX companies, universities, and other organisations and national authorities in Denmark and Sweden. (For a literature overview and list of interviewees, please see the Appendices).

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1. Biosolutions and Power-to-X



The World Needs Sustainable Solutions

Combating climate change and meeting the nutritional needs and energy demands of a growing population without exhausting our planet's resources are among the biggest challenges of our time. Since industrialisation, the fossil economy has created enormous wealth and increased living standards for people all over the world. But serious crises have followed.

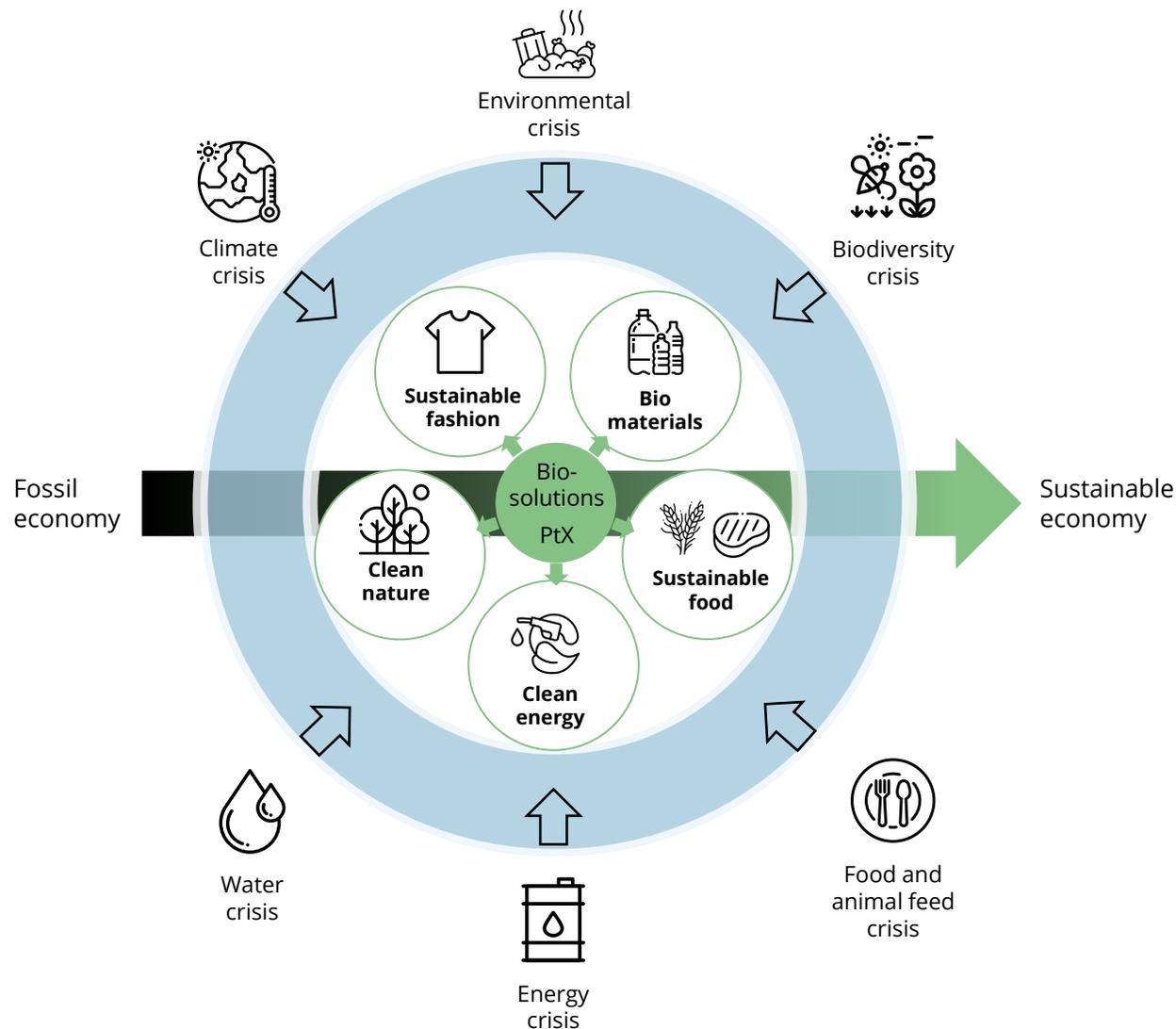
Greenhouse gas emissions have led to significant changes in the world's climate. We are now witnessing global temperature increases and more extreme weather conditions, together with rising sea levels. Consequently, we are witnessing a decline in biodiversity and the extinction of some species, and more places on the globe are becoming uninhabitable. In short, we are facing several crises, all of which have been caused by an economy running on fossil fuels and petrochemical materials.

The way we currently produce and consume is not sustainable. The world's population, which has just reached 8 billion people, would need 1.7 Earths to sustainably support its demands on natural resources (York University, 2022). Our food, clean water, materials and energy requirements will only increase as global population grows. If we continue to produce and consume in the way we do, we will not succeed in combating climate change and in preserving vital resources for future generations.

The crises pictured in the illustration (right) are becoming more and more evident in all parts of the world. Recently, of course, the COVID 19 pandemic and Russia's invasion of Ukraine have further challenged global supply chains and accelerated food and energy crises.

Sustainable solutions are urgently needed. We must move from a fossil fuel based economy to a sustainable alternative. To do this we need to make best use of the scarce bioresources that will be available in a future where fossil resources are not part of the economy. A wide range of sustainable solutions are ready and available for deployment now. But others need more research and development if they are to be scaled up. Now is the time to be smart about how we plan and connect technologies and industries to build environmentally sustainable and economically viable businesses and sectors.

In this chapter, we dive into two technology areas that have proven to have great potential to change the way we produce food, animal feed, energy and chemicals. Biosolutions and Power-to-X (PtX) represent sustainable solutions that will enable us to overcome some of the most serious crises of our time.



Biosolutions – The Industrial Bio-Revolution

Advances in the biological sciences, combined with accelerating developments in computing, data processing and artificial intelligence (AI), are fuelling a new wave of innovation with remarkable decarbonising potential for industries across the economy.

The term “Biosolutions” captures all biotechnological life science solutions applied *outside* the health care sector. Biosolutions are biologically based products and processes that can be used to increase agricultural yields and reduce land use, as well as to provide alternative proteins and colouring for food and animal feed, prevent food waste and minimise demand for chemical plastics and pesticides.

The figure on the right illustrates the range of Biosolutions in the life science sector. The broad scope of the applications makes it useful to divide Biosolutions into subgroups depending on the industry they benefit. The most common subgroups are: manufacturing (white biotech), food ingredients (yellow biotech), agriculture and aquaculture, energy (green biotech), and the environment (grey biotech) (IRIS Group, 2021a).

Biosolutions originate from the scientific art of understanding, predicting and manipulating biological systems. Researchers develop and create microorganisms, together with cells, proteins, bacteria and enzymes, with new properties that form the basis of new bio-based, sustainable products and solutions from bio-refining and fermentation processes.

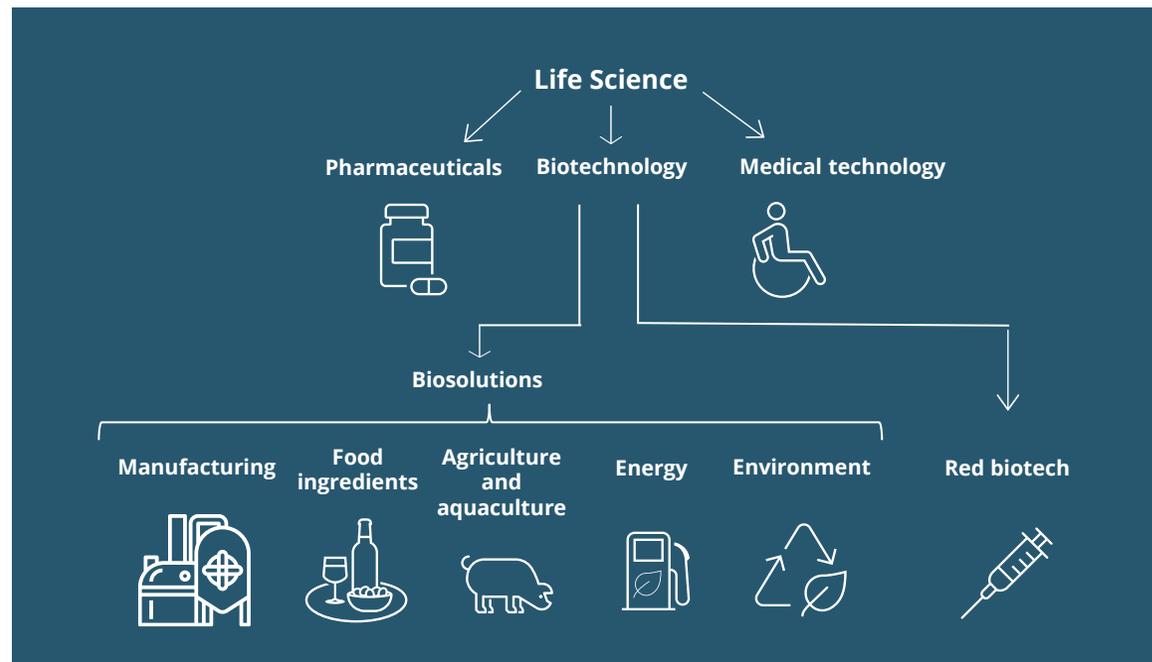
As much as 60% of the physical inputs to the global economy could, in principle, be produced biologically. Approximately one third of the global economy’s inputs are biological. Wood and animals bred for food are examples. The remaining two thirds are nonbiological (e.g. petrochemical plastics and fossil fuels) but they could potentially be replaced by Biosolutions (McKinsey, 2020).

The decarbonising potential of Biosolutions is significant. Towards 2030, the global achievable emission reduction potential of mature, ready to deploy technologies has been calculated at around 4,300 million tons of CO₂ equivalents, corresponding to approximately 8% of current emissions globally, and this is expected to increase after 2030. This potential comes on top of the emissions already being avoided through, for example, the reduced energy consumption enabled by laundry detergents with enzymes and cuts to food waste from products with longer shelf lives. Among the latter, dairy, meat and seafood products must be included, as must ready-made dishes and wine made with fermentation processes using food cultures (Copenhagen Economics, 2022).

Biosolutions are not a new phenomenon. Some, like adding enzymes to laundry detergents, have been around since the end of the 1960s. Thus, Biosolutions range from globally scaled products widely used by people in their everyday lives to early stage research ideas and solutions that need to mature before mass deployment.

Recent advances include a sharp drop in the cost of sequencing DNA and the emergence of new genomic techniques (foremost CRISPR) for editing genes and reprogramming cells. But ultimately, business for Biosolutions companies relies on the ability of those companies to control biological processes precisely up to industrial scale production batches, and on each company’s access to suitable energy, water and basic materials in large volumes.

Biosolutions – Part of the Life Science Sector



Source: IRIS Group, 2021a

Power-to-X – Turning Renewable Energy into Fuels and Chemicals

Power-to-X (PtX) will be essential if we are to develop a carbon neutral society that also meets our increasing demand for energy.

Fossil fuels are being replaced by renewables such as wind, solar and hydro power, and direct electrification of our society is being extended. However, some sectors cannot easily be electrified. Where high amounts of energy are required, or need to be stored, electricity is very often unsuitable or insufficient. For example, aviation, shipping, and heavy ground freight vehicles all require fuel in a liquid or gas form. Equally, industrial plants need energy for production and must move to alternatives to petrochemical products such as pesticides and plastics.

The term “PtX” is used to describe conversion technologies that turn electricity into synthetic fuels (also called e-fuels) and chemicals (see figure, right).*

PtX technologies are being developed, tested and scaled all over the world at a rapid pace. In Denmark, the government has suggested a target of 4-6 GW PtX capacity by 2030 (Danish Ministry of Climate, Energy and Utilities, 2021). For comparison, annual Danish electricity consumption is 4 GW. Thus, the need for electricity from renewable sources will at least double.

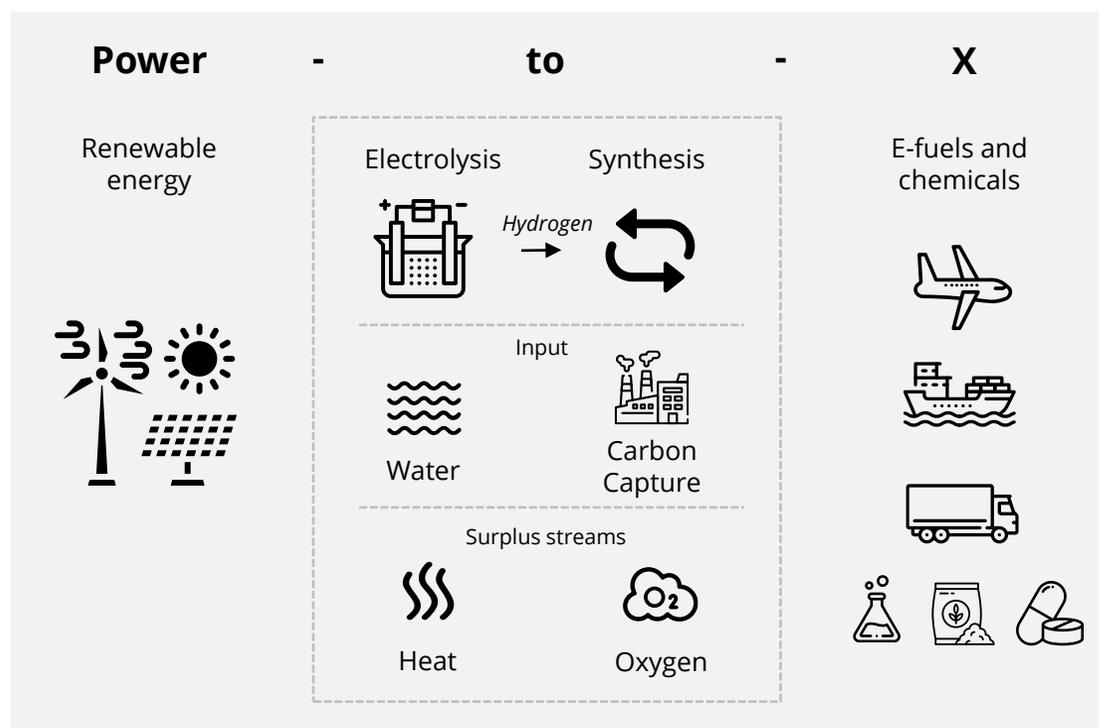
According to our interviewees, operating expenditures are expected to account for around 80% of PtX production costs, making the price of electricity an important parameter. But access to cheap electricity is not the only element to consider in a PtX business case. The figure (right) shows that other resources are an essential part of the process, either as input or surplus streams, and therefore form part of the business case. Thus:

- **Water** is needed in large quantities and extremely high quality as electrolysis uses electricity to split water into hydrogen and oxygen. Electrolyser units are damaged if the water is not ultra-clean. A 1GW electrolyser facility requires the same amount of water as a city of 70,000 people (IRENA 2020). Currently, new techniques are tested that might enable electrolyser units to run on less clean water (see page 15).
- **Carbon capture** technologies and access to biogenic carbon are essential in the synthetic conversion of hydrogen into e-fuels and chemicals.
- **Heat** is generated from electrolysis and synthesis processes. The larger the units, the more heat is produced. Utilisation of surplus heat in the district heating system might be appropriate for large PtX units.

The amounts of surplus heat from large-scale PtX facilities will, however, surpass the needs of district heating. Thus, other ways of cooling PtX facilities will be important.

- **Oxygen** in a very pure form is a by-product when hydrogen is used directly or converted into synthetic fuels to power transportation and industries. Many industries require pure oxygen and are willing to pay PtX facilities for it.

Clearly, then, the location of PtX units is an important factor in building the business case. Access to renewable energy, ultra-clean water and biogenic carbon are essential. An infrastructure that supports clients and commits them to buying both the relevant products (hydrogen, e-fuels, chemicals) and, preferably, surplus streams (heat and oxygen) as well is vital to the business case.



*The term “PtX” is mainly used in Denmark, while “green hydrogen” and “electro fuels” (or simply “e-fuels”) are more common terms abroad.

Sector Coupling Biosolutions and Power-to-X

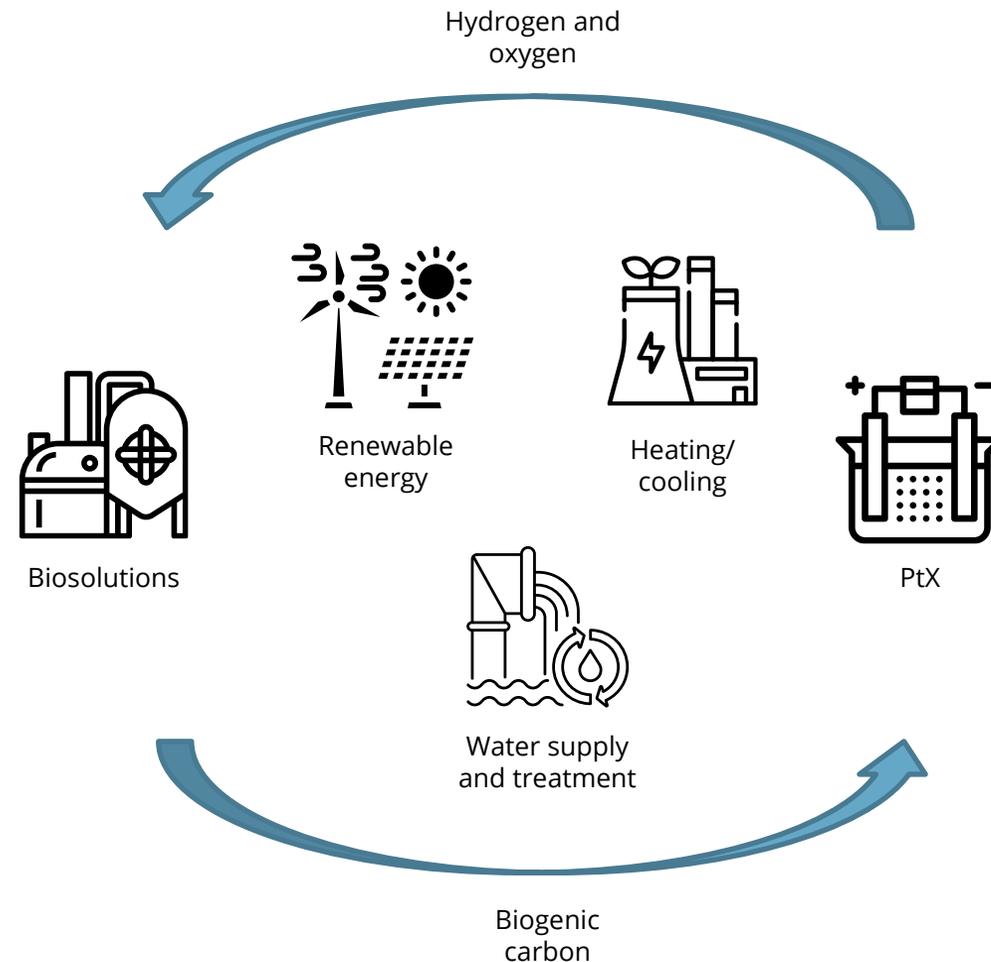
The term “sector coupling” refers to the planned integration of different energy reliant sectors, such as power, transportation, heating, and industry, in order to achieve greater efficiency and sustainability.

As the technologies continue to advance, and with new large-scale production sites being established in the future, the Biosolutions industry and PtX offer real potential for sector coupling that is well worth considering.

The figure to the right illustrates the potential benefits of coupling Biosolutions and PtX facilities. The advantages include:

- *Committed hydrogen buyers.* The Biosolutions industry currently relies on a blend of energy sources, including electricity and natural gas. If large Biosolutions companies commit to using hydrogen from PtX, natural gas can be replaced. At the same time, the PtX producers will secure committed buyers.
- *Shared infrastructure and facilities.* The production of sustainable Biosolutions, e-fuels, and chemicals requires significant amounts of energy and water. Therefore, large-scale production sites must be located in areas with access to reliable high-voltage electricity and suitable water supply. Waste water from Biosolutions and PtX processes needs to be treated, and heating/cooling facilities are necessary to provide steam for Biosolutions companies and to facilitate cooling in PtX facilities. In some cases, the cooling process can utilise heat from PtX in district heating systems.
- *Shared surplus resources.* When hydrogen is separated from water in PtX facilities, pure oxygen is a by-product. Oxygen is a critical ingredient in some new protein sources, so it can be used in the Biosolutions sector. Equally, the sector can provide biogenic carbon that is essential in the synthetic conversion of hydrogen into e-fuels and chemicals.

Overall, the coupling of Biosolutions and PtX production offers a range of advantages that can help us to build a more sustainable, efficient and resilient energy system. However, given that both sectors rely heavily on access to renewable energy and water supply, the infrastructure conditions are a crucial factor.



2. Industrial Symbiosis in Kalundborg



50 Years of Biotech Production and Surplus Sharing

Kalundborg Symbiosis houses production sites for world leading biotech companies including Novo Nordisk, Novozymes, Chr. Hansen and Unibio. It is home to the innovative Kalundborg Utility, a biogas plant, a refinery and the Asnæs Power Plant run by Ørsted.

For more than 50 years the large industrial companies situated in Kalundborg have shared their surplus of excess resources through a symbiotic and circular approach to industry and production. As the companies – both public and private – are physically connected, one company's resource surplus adds value to another. Today, more than 20 different streams of excess resource flow between the companies, creating a symbiotic resource exchange, and adding more resilience and profit to the partners.

In recent years, a local “innovation district” for industry-relevant research and education has emerged in Kalundborg, and the number of partners collaborating in the symbiosis is constantly increasing.

An innovation district is a geographical area where leading-edge anchor institutions and companies cluster and connect with start-ups, business incubators and accelerators. It is usually physically compact, transit-accessible, and technically-wired for connections, and it offers mixed-use housing, office, and retail spaces (Katz & Wagner, 2014).

Innovation districts are a specific manifestation of megatrends that are altering the location preferences of people and firms, and in the process re-conceiving the very links that obtain between economy shaping, place making and social networking.

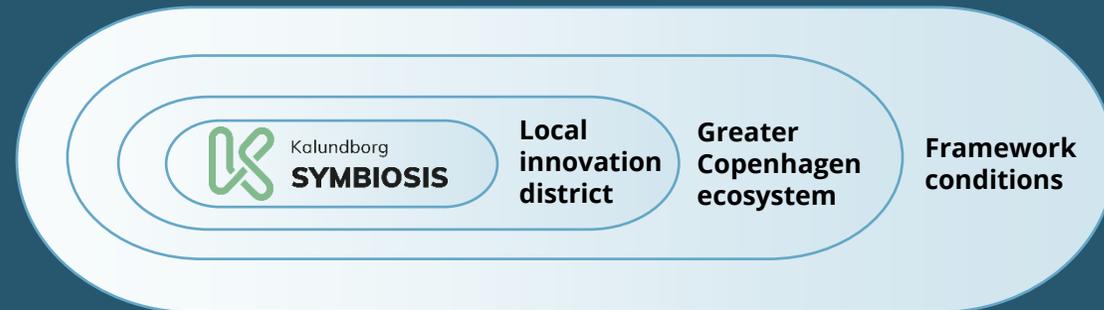
Kalundborg is well on the way in its development of an innovation district around the city's industrial symbiosis. In the years to come, the infrastructure and symbiotic way of thinking in Kalundborg may also fuel a new carbon and PtX economy. For that vision to become a reality, research, and the competencies on which it relies, in the broader Greater Copenhagen ecosystem will be vital, and thus it must be ensured that the framework of conditions in that ecosystem are fit for purpose.

The three chapters of the report that follow are structured in accordance with the figure below.

In Chapter 2, the industrial symbiosis and local innovation district in Kalundborg are described. The infrastructural basis of, and necessary conditions for, PtX in Kalundborg are discussed, and a pilot study – PtX Cluster Zealand – is showcased. Also, a deep dive into the emerging local environment for research and education is presented.

In Chapter 3, the Greater Copenhagen ecosystem is explored. The report offers insights into leading research environments and available labs and facilities of relevance to the Biosolutions and PtX industries located in Denmark and Sweden. Emerging partnerships and cross-border collaboration between Danish and Swedish stakeholders are described, and the state of R&D and venture capital investments in the region is outlined.

Finally, in Chapter 4, “framework conditions” are analysed. We discuss the most important conditions for the development and production of Biosolutions and PtX in Greater Copenhagen, in other words. Our aim is to highlight the biggest challenges and suggest policies that are likely to strengthen the ecosystem and pave the way for green solutions and growth in the entire Greater Copenhagen region.



A World Leading Industrial Symbiosis

A total of 16 private and public companies make up Kalundborg Symbiosis. Together, they employ 4,500 people.

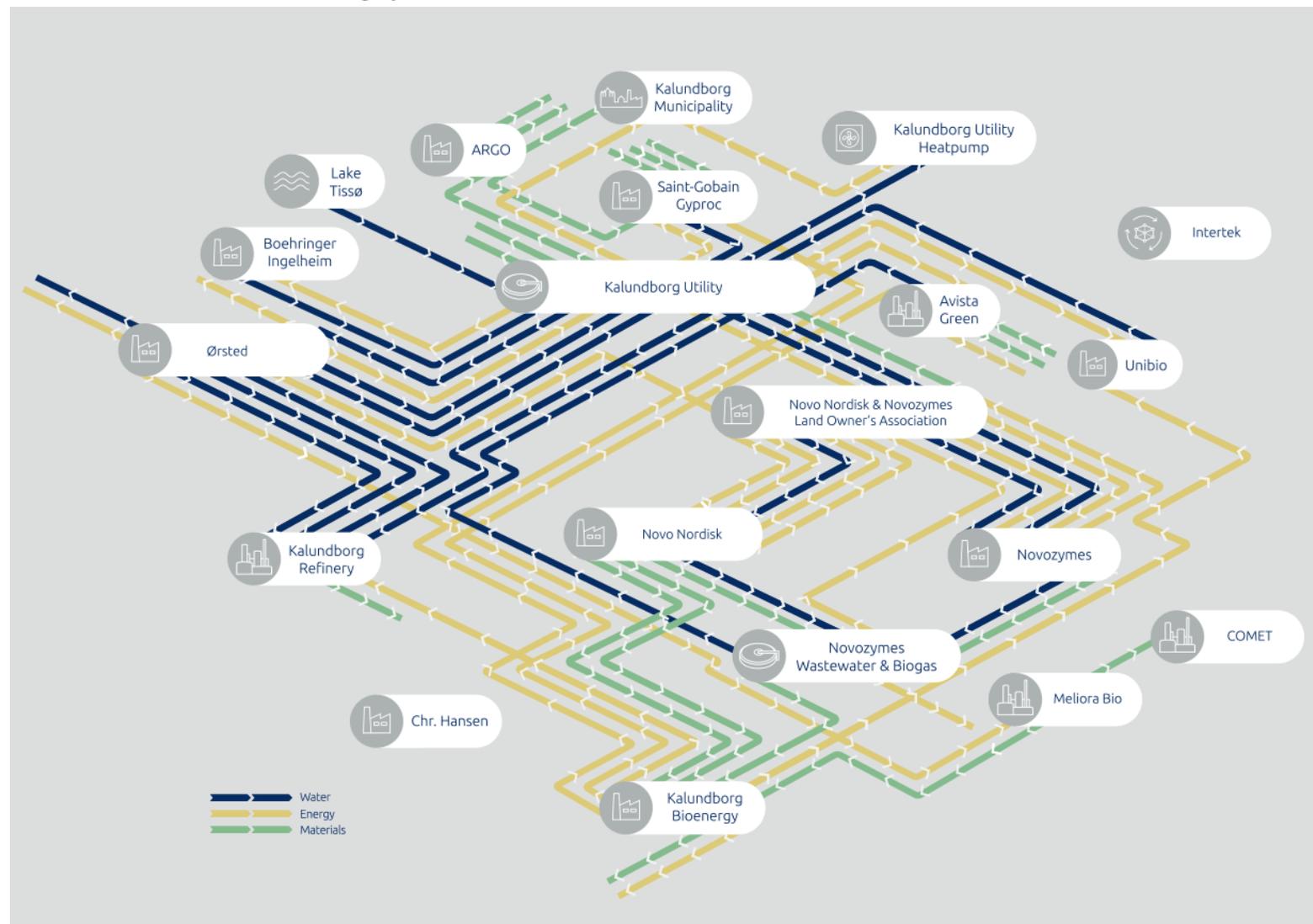
The companies enjoy close cross-sectoral collaboration, in which they share three types of surplus resources (illustrated with blue, yellow and green lines in the figure to the right). The shared resources are:

- *Water* of different qualities, including de-ionised water, cooling water, surface water, wastewater, etc.
- *Energy*, including steam, district heating, biomethane, electricity, etc.
- *Materials*, including ethanol waste, yeast slurry, novogro, etc.

All of the resource flows depicted in the figure have been shown to offer sustainable and successful solutions for the companies involved – both financially, environmentally and branding-wise. In the resource flows, the relevant technologies were mature, and companies saw the potential to benefit from mutual and binding partnerships. They benefited in this way, for instance, when they found ways to recycle excess resources rather than paying landfill fees.

Some of the most significant resource flows in the symbiotic network are the material flows shown at the bottom of the figure. Here, ethanol waste, yeast slurry and novogro from Novo Nordisk and Novozymes sites flow to Kalundborg Biorefinery, where they are upgraded to become fertilisers and biomethane (a gas with qualities equivalent to those of natural gas). The biomethane is then distributed via the natural gas grid to Kalundborg Refinery and other consumers, while the fertilisers are sold for agricultural purposes.

Resource streams in Kalundborg Symbiosis



Source: Kalundborg Symbiosis

Biosolutions Zealand – an International Industry Lighthouse in Biosolutions

Biosolutions Zealand is a strategic initiative designed to make Zealand and its surrounding islands a world-leading innovation region within Biosolutions development. The overall ambition is to support sustainable biotechnology development that addresses global and local climate change while also creating economic growth, jobs and exports.

Zealand is a nature biosolution hotspot. It already has a large concentration of biotechnology companies, many of which are located in Kalundborg, and together these create a unique environment of knowledge and skills that can be further developed.

The Biosolutions Zealand initiative is managed by a broad consortium of public and private partners, including knowledge institutions, leading Biosolutions corporates, municipalities, cluster organisations, and others. It runs from 2022 to 2025 and is supported with EUR 8 million funding from REACT-EU. The consortium has applied for additional funding in order to extend and continue the project. See the partners below.



The initiative is organised around three themes, each of which covers a range of core activities. Since it is an ongoing project, not all of the activities have been launched as yet. The themes and their associated activities are as follows:

- *Developing a coherent ecosystem for innovation and entrepreneurship.* An important part of the initiative is to develop several physical test and demonstration facilities in the Zealand region where Biosolutions companies can trial, validate and develop their technologies and products. The facilities address different technologies and Technology Readiness Levels (TRLs), thereby helping companies to move smoothly from idea to market – and to overcome “the valley of death” (see more on labs and test facilities at p. 24). In addition to the physical facilities, core activities within this theme include the establishment of:
 - Collaborative projects between SMEs, large companies and knowledge institutions focusing on innovation within food, animal feed, ingredients, etc.
 - A Biosolutions Launch Pad where Biosolutions companies are offered networking and advice on typical issues such as technology development, market validation, regulation, financing, etc.
- *Securing access to suitably qualified labour for the region's Biosolutions companies.* This theme focuses on establishing new MSc programmes in Biosolutions as well as securing further education within digitalisation that targets operators, laboratory technicians, bioanalysts, etc. Specific efforts to attract and retain students on sector-relevant educational programmes have been made (see more on education in the innovation district of Kalundborg at p. 16-18).
- *Attracting international startups, companies, employees and investments.* This theme includes marketing activities designed to raise international awareness of Zealand as a Biosolutions powerhouse offering unique industry framework conditions. The aim is to attract companies, skills, investments, etc. Initiatives that prepare Danish Biosolutions companies for international exports are also expected to be launched.

The PtX Potential in Kalundborg

The Danish Energy Agency has assessed that PtX is an essential part of achieving the Government's 70% emissions reduction goal by 2030 and will play a particularly important role in the achievement of the climate neutrality goal for 2050.

PtX facilities are expected to expand gradually, as the technologies on which PtX relies are not yet commercially viable. In Denmark, 28 PtX innovation projects have begun with the support of national and EU funding. One of these – PtX Cluster Zealand – is in Kalundborg (this project is described on the next page).

The relationship between PtX and the infrastructure and symbiotic mindset in Kalundborg is of interest here. Electricity and tariffs account for the bulk of the costs in PtX production. No matter where large-scale PtX production sites are located in the future, expansion of renewable energy production and grid capacity will be needed. But as explained above, on page 8, other elements also impact the business case and the sustainability of PtX.

First, as water is the main input in PtX, it is necessary to consider the types of water used and the sources of these. The ideal location for a PtX facility is one with access to a water supply that is reliable and not subject to competitive use. Surface water ticks both of those boxes. So do impaired groundwater and treated wastewater effluent. In fact, it is precisely because the water must be extremely clean when it enters the electrolyser that less clean sources can be used. All water has to be meticulously pre-treated in any case, so whether it is more or less contaminated to begin with matters less (Ramboll, 2022). Kalundborg Utility has many years experience in treating and supplying surface water to industries in Kalundborg from the nearby Lake Tissø. It is also the only utility service in Denmark with an operational desalination plant that converts seawater into drinking water. PtX production in Kalundborg would require a large expansion of the present water supply and treatment facilities, not least because the existing companies in the Symbiosis plan to expand in the years to come. But our interviewees seemed to confirm that Kalundborg Utility has the know-how and experience to become a key player in a large-scale PtX production site.

Second, the main output of electrolysis is hydrogen. This can either be used directly or synthesised into e-fuels or chemicals. The synthetic process requires biogenic carbon, i.e. carbon derived from organic rather than fossil material. Such carbon could be captured from CO₂ in biogas plants, or in biomass-fuelled power plants, and utilised for PtX – this would be part of the process known as Carbon Capture, Utilisation and Storage (CCUS). Thus the biotech production sites, biogas and power plants in the Kalundborg Symbiosis could potentially be part of a new carbon economy.

Some interviewees argued that the carbon economy is likely to grow more rapidly than a large-scale PtX economy. Biogenic and sustainable carbon is expected to become a limited resource, as the world's sustainable biomass resources are limited and biomass is also needed for food, animal feed and other purposes. Given this, we should start capturing biogenic carbon and store it for later use (CCUS). Subterranean structures in Denmark are generally assessed as fit for substructural carbon storage, and two sites close to Kalundborg – the subterrain around Havnsø 20 km northwest of Kalundborg and the existing subsoil natural gas storage in Stenlille about 40 km southwest of Kalundborg – have been identified as ideal.

Finally, sector coupling potentially offers a secondary revenue stream from PtX production because electrolysis generates oxygen and heat as surplus streams. Providing oxygen to industry or wastewater treatment plants, or directing excess heat into district heating, could improve the business case.

Kalundborg Utility operates one of Northern Europe's largest and most advanced treatment plants, which relies on liquefied oxygen. More generally, for some companies in Kalundborg Symbiosis, oxygen is the single most expensive raw material in their production. In interviews, representatives from industry and the utility service confirmed an interest in using surplus oxygen from any future PtX production.

As stated, excess heat from PtX production could be integrated with the district heating system. Today, Kalundborg Utility distributes district heating to approximately 5,050 households in Kalundborg city. In the future large volumes of excess heat could potentially be distributed to the larger cities on Zealand, like Holbæk, that currently rely on natural gas for heating. However, the amounts of surplus heat from large-scale PtX facilities will surpass the needs of district heating even when the distribution is extended to more cities. Thus, other ways of cooling PtX facilities need to be in place. The Asnæs power plant in Kalundborg was built with 1.5 GW capacity, but as wind and solar power have taken over most electricity production in Denmark, only one sixth of its capacity is in use today. Nonetheless, the power plant still has cooling capacity for 1.5 GW which could be used for cooling PtX facilities.

In short, Kalundborg offers genuine potential for the beneficial coupling of PtX production with industrial symbiosis, with advantages flowing from shared resources and joint access to the existing infrastructure. A first step in exploration of the potential has been taken with the PtX Cluster Zealand project described on the next page.

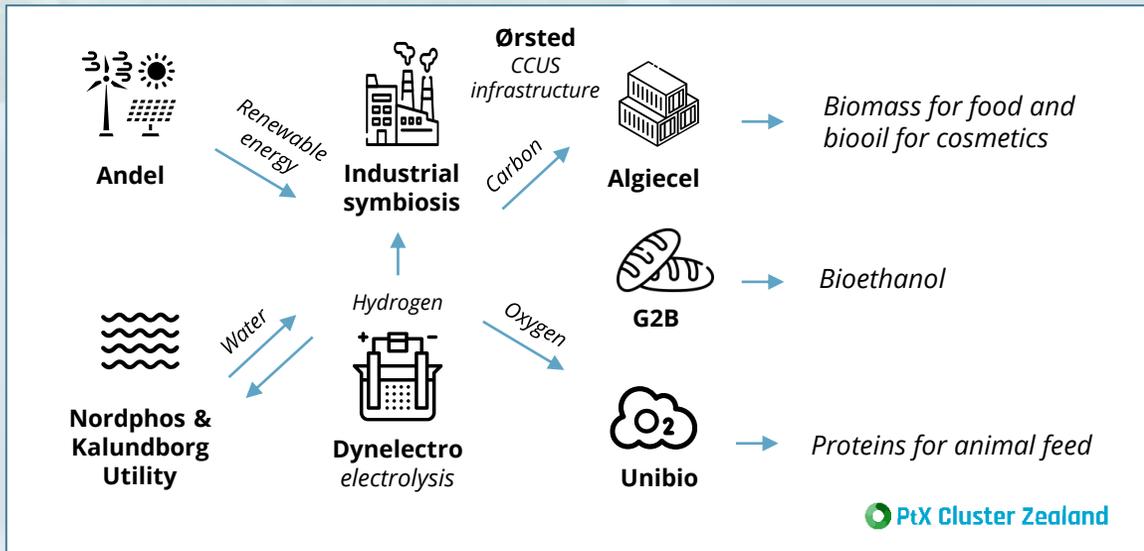
PtX Cluster Zealand

PtX Cluster Zealand is an innovation project aiming to mature, test and scale up new technologies that may enable highly efficient electrolysis – and contribute to the construction of a more commercially viable business case around PtX.

The project also closely examines the opportunities to optimise green energy supply for PtX facilities and the potential value of PtX facilities’ excess resources.

The project is being conducted by a broad consortium of private and public partners. Key actors include five high tech companies who, drawing on their own technology, help to build the PtX business case. The technology partners are supported by a broader group of utility companies, knowledge institutions and business promotion officers (including Business Hub Zealand, Knowledge Hub Zealand, Kalundborg Symbiosis and Energy Cluster Denmark).

The project runs from April 2022 to August 2023. It has received around EUR 3.3 million in funding from The European Regional Development Fund.



Key project activities

The focal point of the project is the construction of a 20 feet electrolysis prototype (30 KW) in Kalundborg and the testing of a patented electrolysis technology developed by the university spinout Dynelectro. The technology enables a mix of alternating current (AC) and direct current (DC) for electrolysis, which prolongs life expectancy of the so-called “SOE-stacks” used in electrolysis – and, hence, reduces hydrogen production costs by 20%.

Aside from Dynelectro, four other tech companies, which either take or supply resources to the PtX plant, participate in the project. These are:

- *Unibio*: uses oxygen from electrolysis in production of proteins in animal feed.
- *Nordphos*: delivers ultra-clean water and purified cooling water for electrolysis.
- *Algiecel*: captures carbon and transforms it into biomass for food and dietary supplements and bio-oil for cosmetics.
- *G2B*: plans to establish a biorefinery plant in Kalundborg for sustainable ethanol production.

Beyond these actors, the remaining partners contribute resources, including expertise knowledge, project management and resource flows, in order to ensure effective project implementation and long-term anchoring.

The utility companies Kalundborg Utility and Andel deliver water and energy to the PtX plant. Ørsted investigates potential infrastructures for CCUS in the Kalundborg area, and the Chemical Engineering department at the Technical University of Denmark (DTU) helps project partners to explore ways to adapt and integrate each others’ technologies.

Finally, Business Hub Zealand and Knowledge Hub Zealand act as project managers and focus on a combination of business development, technology commercialisation and the integration of PtX in Kalundborg’s existing industrial symbiosis.

Campus Kalundborg – an Emerging Environment for Industry Relevant Research and Education

Campus Kalundborg is located in the eastern part of the city. The campus is adjacent to Novo Nordisk and Novozymes, which are major players in the industrial symbiosis and collaborate closely with local educational institutions. In 2018, access to the area by public transportation was improved with the establishment of the train station Kalundborg Øst Station – biotekbyen.

The campus currently houses three educational institutions: University College (UC) Absalon, Helix Lab and EUC Northeast Zealand. These offer vocational and higher education relevant to local industries, including engineering degrees in biotechnology and mechanical technology and training for electricians and process operators.

Several other educational institutions are planning to open programmes on the campus in the coming years. In 2023, The Mechanical Engineering School Copenhagen and The Royal Danish Academy are enrolling students in mechanical engineering and architecture programmes. And in 2023/2024, DTU and the University of Copenhagen open new Master's programmes in biomanufacturing and Biosolutions. The former is a 4-year business programme on which students work part-time while studying. The latter is a 2-year programme developed in close cooperation with local industry actors who need engineers and academics with an understanding of biotechnological solutions within the field of food and the environment.

The campus area was opened in 2021, but efforts to build up a flourishing educational environment within biotech can be traced back to 2016. At that time, Kalundborg only offered vocational training (aside from primary school and upper secondary education). Local actors identified a common challenge in attracting and retaining a highly skilled workforce and saw the potential to build up industry-relevant education locally.

In order to realise this idea, a partnership between Knowledge Hub Zealand and Biotekbyen was established. This involved actors from Kalundborg Symbiosis, regional educational institutions, Kalundborg Municipality and others with a shared vision of transforming Kalundborg into an *“international biocluster for industry 4.0 bioproduction and industrial sustainability research, education and innovation by 2030”*.

The partners work together in various ways to grow suitably qualified labour locally. For instance, they support educational institutions in designing educational programmes for the area by clarifying industry needs, and they mediate collaboration between students and industry through internships, project work and matchmaking arrangements. Finally, they hold events to raise awareness of local education (see more on p. 17).



Campus development

- 20-** – Industrial Design (MSc), DTU and Royal Danish Academy (in the planning)
- 2024** – Biosolutions (MSc), University of Copenhagen
- 2023** – Biomanufacturing (MSc), DTU
- 2023** – Architecture (BSc and MSc), The Royal Danish Academy
- 2023** – Mechanical Engineering (BSc), Mechanical Engineering School Copenhagen
- 2022** – Opening of Helix Lab
- 2021** – Opening of UC Absalon's campus area
- 2021** – Mechanical Technology Engineering Bachelor (BSc), UC Absalon
- 2018** – Electrician (vocational), EUC Northwest Zealand
- 2018** – Bioanalysis – lab technician (BSc), UC Absalon
- 2017** – Engineering in Biotechnology (BSc), UC Absalon
- 2016** – Knowledge Hub Zealand is established

Helix Lab – Connects Research and Industry through MSc Students' Project Work

Helix Lab is a research and education centre located next to UC Absalon at Kalundborg Campus, which opened in the spring semester of 2022. Helix Lab aims to build a dynamic community of students, researchers and future candidates for employment in the biotech industry in Kalundborg.

The core activity of the centre is to facilitate collaborative Master's thesis projects involving MSc students from universities (in Denmark and abroad) and the local industry. Master's students are affiliated to Helix Lab as a "Helix Lab Fellows" for a period of 5-10 months during which they do their thesis project work. A Helix Lab Fellowship gives access to:

- An academic supervisor from the student's home university and an industrial supervisor from the company with which the student collaborates.
- Four Industry 4.0 research laboratories – including a process laboratory, an automation and robotics laboratory, a rapid prototyping laboratory and an analytical laboratory.
- Free housing at Kalundborg Kollegium during their stay. Helix Lab Fellows are required to live in Kalundborg during their project work.
- A Fellows Programme with guest lectures, site visits and social activities.
- Other activities in the Helix Lab community, such as tech talks, networking events and gallery walks with poster presentations of their thesis results.

Ideas for Helix Lab Master's projects are developed by local industry specialists and researchers from Danish universities in collaboration. Twice a year, Helix Lab facilitates matchmaking events at which local industry actors pitch ideas and challenges for thesis projects which are refined in close dialogue with researchers. Researchers subsequently present project ideas for their students. Applications for Helix Lab Fellowships are submitted by the academic supervisor and the industrial supervisor together with the MSc student. The Fellowships are awarded by the Helix Lab Board of Directors.

In addition to arranging matchmaking events around Master's projects, Helix Lab supports contact between academic and industry supervisors in network meetings several times a year. These "focus group" meetings gather a smaller group of supervisors on specific subjects of interest (such as fermentation, downstream processing, etc.), while common network meetings gather all supervisors.

The Helix Lab initiative is financed by Novo Nordisk Foundation, Novo Nordisk and Novozymes, and governed by UC Absalon.



Helix Lab partners and collaborators



An Increasing Number of Students are Admitted to Programmes at Campus Kalundborg

Following the formalisation of efforts to develop new provision in higher education in Kalundborg in 2016, an increasing number of students have been enrolled on programmes at Campus Kalundborg (see table, right).

In 2022, 166 students (including MScs at Helix Lab) were enrolled on campus – a substantial rise from the 46 students in 2017. Hence, the partnership behind Knowledge Hub Zealand and Biotekbyen is well on its way to realising the ambition of attracting between 300 and 500 students into educational programmes at Campus Kalundborg.

Several initiatives have been launched to raise awareness of educational programmes in Kalundborg among young people who have an interest in science and biotechnology. Examples include:

- Biotech Championships.** This is an annual competition in which young students from upper secondary schools from all over the country are invited to resolve a company-specific challenge. The challenge is tackled within regular lessons, and the results are judged and presented by a panel of representatives from local industry and educational institutions. The competition is organised by Knowledge Hub Zealand and UC Absalon.
- #Bio2Me.** This aims to ensure that more students enrol and graduate from programmes in biotechnology and mechanical technology in Region Zealand. Project activities include scouting among upper secondary and vocational education students, who are offered competency assessments, career guidance and customised entrance courses. Students who decide to enrol in one of the programmes are offered a study. They are also assigned an industry mentor during their studies to improve retention rates and to ease their path into the labour market after graduation. The project is organised by UC Absalon.
- Virtual Biosolutions Education Day.** This is an online webinar involving five Biosolutions-related educational programmes that are offered at UC Absalon and Roskilde University. The target group is international young people considering studying in Denmark. Ahead of the webinar, a teaser video about the industrial labour market for Biosolutions graduates is released. This presents interviews with international leaders and employees at companies from the industry in Kalundborg, including Kalundborg Utility and NNE Pharmaplan. The webinar was held for the first time in February 2023 and had 27 participants from 17 countries.



Students enrolled in programmes at Campus Kalundborg (2017-23)

| | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|-----------|-----------|-----------|-----------|-----------|------------|----------|
| UC Absalon | | | | | | | |
| Biotechnology DK | 26 | 13 | 16 | 21 | 21 | 21 | - |
| Biotechnology INT | 16 | 16 | 24 | 22 | 30 | 36 | - |
| Bioanalysis | - | 17 | 19 | 19 | 31 | 30 | - |
| Mechanical Technology | - | - | - | 12 | 15 | 18 | - |
| Mechanical Engineering School Copenhagen | | | | | | | |
| Mechanical Engineering | - | - | - | - | - | - | 7 |
| Helix Lab | | | | | | | |
| MSc students | - | - | - | - | - | 19 | 14 |
| Total | 42 | 46 | 59 | 74 | 97 | 124 | - |

Note: Figures from 2023 only include programmes with winter enrollment.

Actors Promoting Biosolutions and PtX Innovation in Region Zealand

Kalundborg is well on the way to developing an innovation district around the industrial biotech symbiosis. In the years to come, its infrastructure and symbiotic approach may also have the potential to fuel a new carbon and PtX economy.

Promoting knowledge and innovation is essential. The ability to attract competencies and create a thriving business and startup environment are vital elements of an innovation district. Several actors are engaged in this agenda.

Knowledge Hub Zealand (KHZ)

KHZ supports and promotes education, knowledge and development in the Zealand Region, primarily in the biotechnology sector.

KHZ works closely together with, and houses the secretariat for, Biotekbyen, which is a unique partnership between local industry, educational institutions and other public actors including Kalundborg Symbiosis. KHZ and Biotekbyen have a shared vision of transforming Kalundborg into an *“international biocluster for industry 4.0 bioproduction and industrial sustainability research, education and innovation by 2030”*.

KHZ carries out a range of projects and activities in pursuit of its ambition. Attracting new educational programmes and students to Kalundborg, mediating collaborations between students/researchers and the local industry, supporting the development of a coherent testing infrastructure for bio-refinement and fermentation in the Zealand Region – these are just a few examples of the organisation's activities.

Business Hub Zealand

Business Hub Zealand is one of six cross-municipal business centres that provide business support for Danish and foreign entrepreneurs and SMEs located in the Zealand Region.

Business Hub Zealand employs several business developers offering free-of-charge individual and impartial sparring sessions to companies that wish to develop and grow. Furthermore, it provides information to companies and helps them to enter national and regional business promotion programmes focusing on themes such as digitalisation, innovation, sustainability, leadership and entrepreneurship.

Additionally, Business Hub Zealand initiates and implements projects aiming to ensure that business framework conditions in a broad range of sectors including Biosolutions and PtX are put in place. For instance, it provides sparring sessions on business development to SMEs participating in the PtX Cluster Zealand project.

Cluster organisations

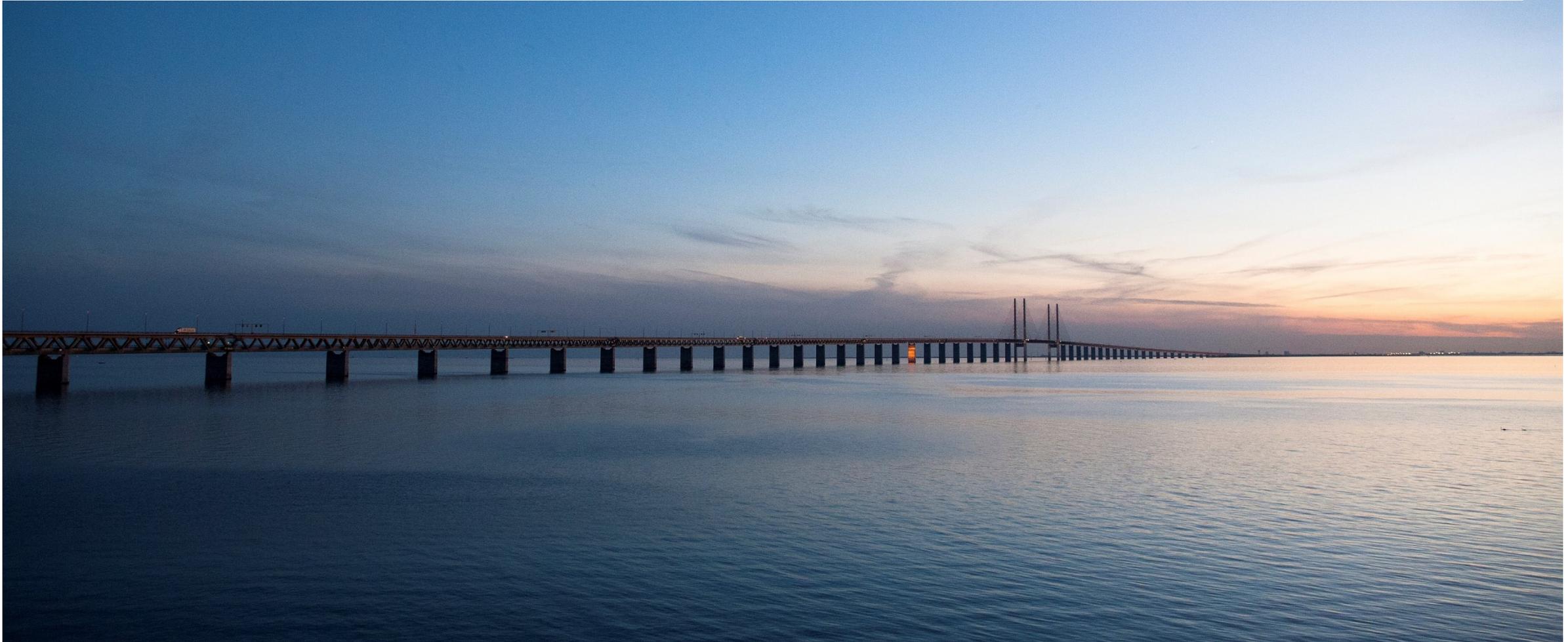
Three national cluster organisations are engaged in the development of the industrial symbiosis in Kalundborg. Cluster organisations bring together companies, research institutions and public organisations in projects that aim to promote innovation and collaboration in various sectors. They are the gateway to networking and the development of new business ideas, as well as funding opportunities in Denmark.

Food & Bio Cluster Denmark is strongly engaged in the development of Biosolutions. Thus it is a critical partner in Biosolutions Zealand – the international industry lighthouse (see page 13).

Danish Life Science Cluster collaborates with KHZ. Since 2022, it has had an office in Kalundborg. The focus is on commercial scaling, attracting startups and obtaining large EU grants for biotech development.

Energy Cluster Denmark is part of the innovation project PtX Cluster Zealand (see page 15). It is involved in no fewer than 28 PtX projects across Denmark, affording it a unique insight into early-stage results and opportunities to facilitate knowledge sharing in this field.

3. The Greater Copenhagen Ecosystem



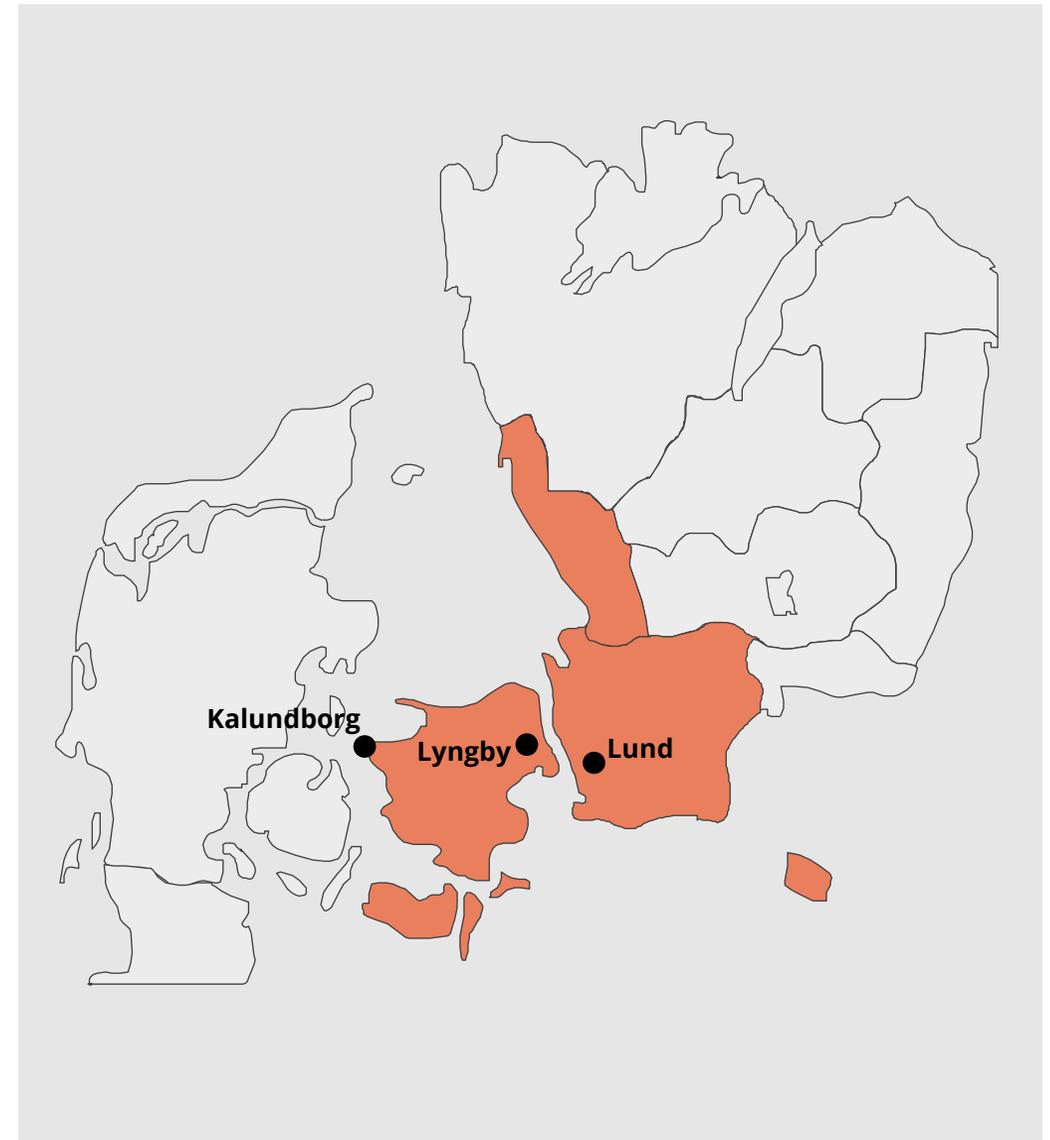
The Greater Copenhagen Ecosystem

The industrial symbiosis in Kalundborg and the local innovation district surrounding it are not islands. On the contrary, they tap into the metropolitan region of Greater Copenhagen, which is an area of significant economic growth: the region's GDP has grown by around 30% over the past 10 years and amounted to more than EUR 200 billion in 2020, which is on a par with the Stockholm metropolitan area (Greater Copenhagen, 2023). Greater Copenhagen contains various resources of value to companies working with Biosolutions and PtX. These include:

- *Climate-ambitious authorities.* A total of 85 municipalities and four regions have come together under the auspices of Greater Copenhagen with the goal of becoming a globally leading metropolitan region in terms of green transition. This includes an ambition to achieve carbon neutrality by 2030, which has been formulated in the partnership's green charter. The charter sets out other initiatives designed to realise the overall goal, including the Nordic Bio Solution Hub (see next page).
- *Excellent research.* Top universities and knowledge institutions lie in Greater Copenhagen, of which several conduct research in electrolysis, biotechnology and other basic sciences applied in the Biosolutions sector. Some of the most significant research environments are distributed across universities like the Technical University of Denmark (located in Lyngby) and Lund University.
- *Flourishing industry.* Life science (including pharma and medtech) is a cornerstone of the Danish economy. The sector had an export value of EUR 20 billion in 2020 and invested 6% of its turnover in R&D in 2018. Globally leading biotech companies such as Chr. Hansen, Novo Nordisk and Alfa Laval have headquarters and development and production facilities in Greater Copenhagen. As regards energy, the region also houses leading companies, including Ørsted, with active investments in both PtX and CCUS.
- *High level of R&D investments.* In 2019 funds equivalent to almost 4% of GDP in Greater Copenhagen were invested in R&D in the private and public sector (Greater Copenhagen, 2023). The region is also home to significant private foundations, supporting R&D, that aim to promote health and sustainability. The Novo Nordisk Foundation established a research facility, the Center for Biosustainability, at DTU in 2011. The Villum Foundation has recently invested in an innovation centre for PtX technologies that is also based at DTU.
- *Test and scaling facilities.* A coherent test and demonstration infrastructure for Biosolutions is under construction in the Zealand region, and Lund houses state of the art X-ray facilities with multiple applications, including in the life sciences and biotech.

On the following pages, we will detail some of the resources available in Greater Copenhagen – more specifically, university research environments, testing facilities and investments.

Greater Copenhagen geography and its biotech hotspots



The Nordic Bio Solution Hub

The Nordic Bio Solution Hub is a partnership between 16 public and private actors in the Greater Copenhagen region. It aims to ensure that potentials for innovation and cooperation across actors within the Biosolutions sector are realised in the Greater Copenhagen area. In particular, the partnership works to:

- Support the establishment of regional, state of the art test and scaling facilities that will help promising Biosolutions entrepreneurs to survive the “valley of death”.
- Facilitate cooperation and networking between large enterprises, entrepreneurs, authorities, universities and other research institutions in order to:
 - Enhance general framework conditions – including regulation and standards – of relevance to the entire Biosolutions sector.
 - Support better documentation and marketing of new products and solutions based on biotechnology, such as alternative proteins and biobased materials and pesticides.
- Attract more external funding for sector development by coordinating and mediating relevant consortium partners in major applications for funding.

Actors in the partnership meet four times a year to share knowledge and discuss the progress of ongoing activities that contribute to realisation of the partnership’s goals.

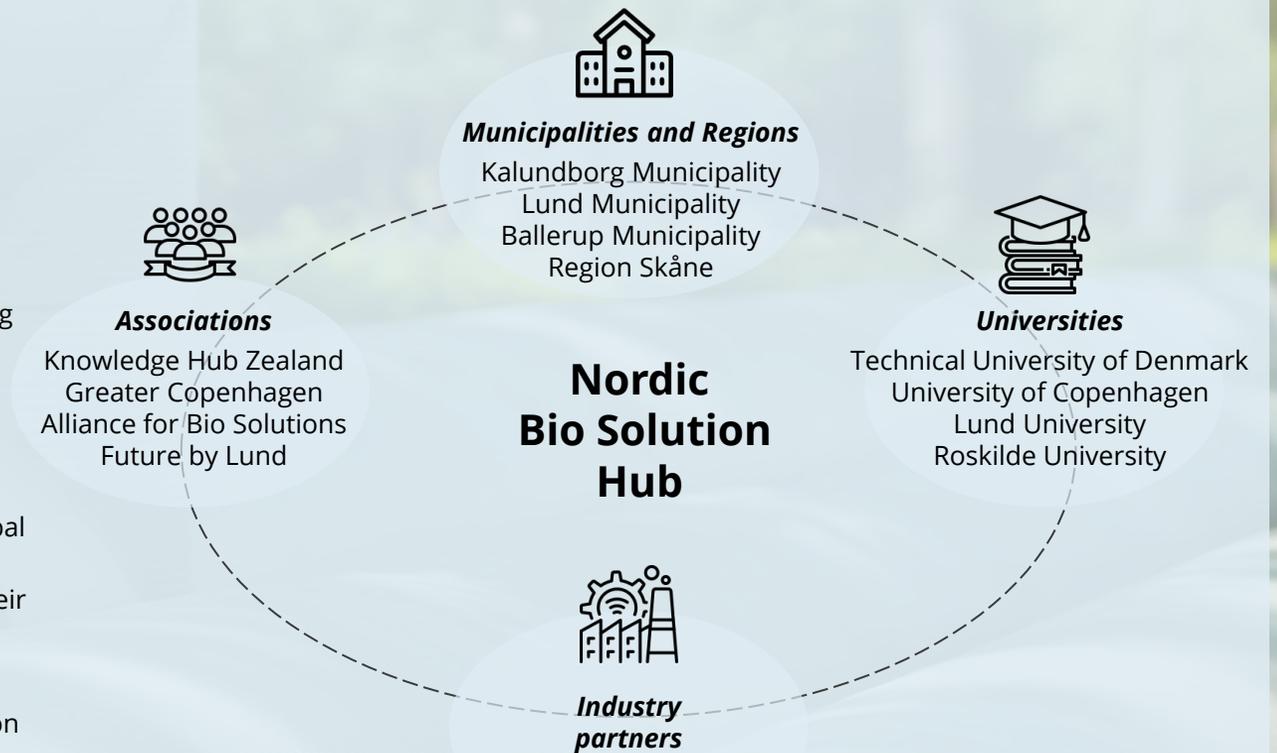
Why was Nordic Bio Solution Hub established?

Biosolutions are important enablers of the wider mission to meet the challenges of global climate change and hit European carbon neutrality targets by 2050. Since Denmark and Sweden are already in a global position of strength within biotechnology (in terms of their research and established industries), they have the potential to become world leading knowledge hubs.

However, global competition is fierce. US investments in biotech research and innovation is five times the size of the EU’s. Hence, if full sector potential is to become a reality, stakeholders on both sides of Oresund must agree to make Biosolutions an area of

political priority – and to pool resources and speak with one voice within the framework of the Nordic Bio Solution Hub.

Partners behind the Nordic Bio Solution Hub include municipalities, universities, leading Biosolutions companies in the Greater Copenhagen area, industry organisations and non-profit organisations. The current partners are listed below – more are expected to join.



University Research Environments

Biosolutions and PtX are both research intensive fields. Ideas for new bio or energy solutions emerge from basic research – hence, universities and other knowledge institutions play a key role in these sectors.

Greater Copenhagen is home to several universities with major research environments within sustainable energy technologies and the basic biological sciences (such as genetics, microbiology, biotechnology, etc.), that are applied in the Biosolutions field. The most significant are the Technical University of Denmark, University of Copenhagen, Lund University and Swedish University of Agricultural Sciences (see summaries, right).

The first two of these, especially, have research strengths in industrial Biosolutions (white biotech), food and ingredients (yellow biotech) and agriculture (green biotech). For instance, at DTU's Biosustain around 100 researchers are working with research and innovation enabling large-scale production of sustainable foods, sustainable bio-chemicals and natural products.

The last two of the universities listed have research strengths in industrial Biosolutions, biofuels and agriculture. Researchers engaged in biobased products and processes across different departments at Lund University are gathered in the Biobased Industry Research Center (LUBIRC).

The region is also home to other knowledge institutions with smaller groups of researchers working in various areas of biotechnology. For instance, UC Absalon and Kristianstad University both have research environments focusing on the development of healthy, sustainable foods. Roskilde University has a research group focusing on environmental dynamics, including biological production based on micro algae, etc.

Technical University of Denmark (DTU)



DTU ranks third in the world in biotechnology* and hosts several divisions that conduct research of relevance to the Biosolutions sector. The most significant are Biosustain, Bioengineering and Chemical Engineering. Biosustain is an interdisciplinary research centre focusing on sustainable chemicals, natural products and microbial food. Bioengineering and Chemical Engineering have specialised competencies and facilities in fermentation and protein purification.

DTU also has strong research environments in energy. In particular, the Department for Energy Conversion and Storage conducts research into core PtX technologies, including alkaline and solid oxide electrolysis technologies for hydrogen production.

Lund University



In Lund University several departments research biobased products and processes. Foremost is the Division of Biotechnology and Food Technology.

Most researchers are brought together in the Biobased Industry Research Center (LUBIRC). Represented research areas include bioprocess technology, enzymatic and microbial catalysis, fermentation processes, biomass fractionation and bioremediation.

Lund University has also established an interdisciplinary research network focusing on energy transition, in which researchers across departments at the technical faculty collaborate on projects connected with electrification, energy storage and sector couplings.

University of Copenhagen



At the University of Copenhagen, biotechnological research with applications in food and agriculture is conducted in the Department of Food Science and the Department of Plant and Environmental Sciences.

Research in the Department of Food Science ranges widely, but the core competencies of the department include food microbiology, fermentation, plant-based and foods. The Department of Plant and Environmental Sciences works on interactions between micro-organisms in soil and plants, including plant protection.

The Copenhagen Plant Science Centre conducts interdisciplinary research on how to employ plants in foods, animal feed and materials.

Swedish University of Agricultural Sciences



The Swedish University of Agricultural Sciences has several campuses. In the southern part of the country, Alnarp Campus houses three departments that conduct biotechnology research to be applied in agriculture. The departments include Plant Breeding, Plant Protection Biology and Biosystems and Technology.

Leading research areas in these departments include plant genetics and breeding (including gene editing and modification), biological resistance, and cropping system ecology. Much of the research is conducted at SLU Grogrund, a centre that acts as a knowledge hub for sustainable Swedish plant breeding. The centre is hosted by the Department of Plant Breeding.

*According to Shanghai Ranking, DTU is surpassed only by Harvard University and MIT.

Labs and Facilities

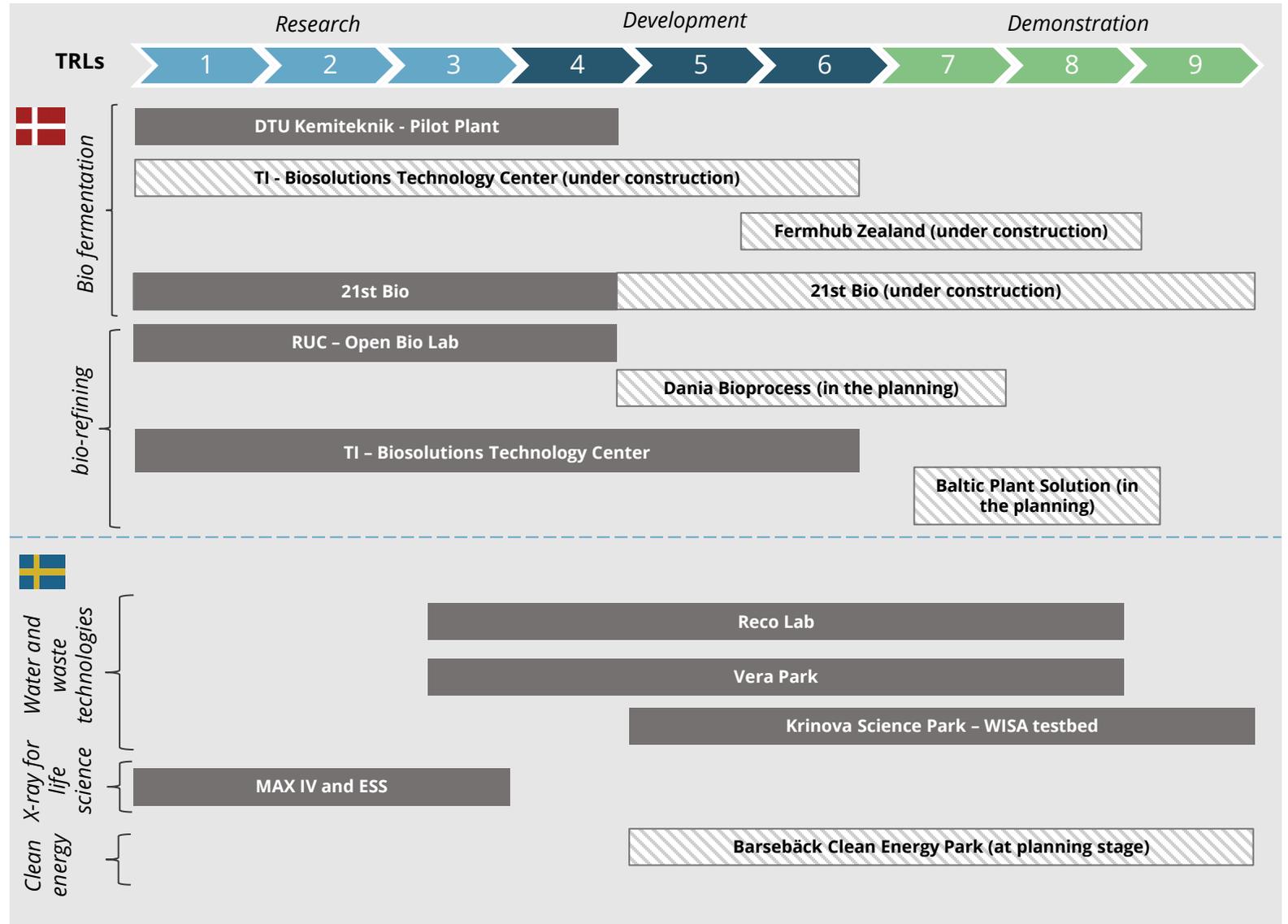
Denmark and Southern Sweden house several types of physical labs and facilities. In these, industry, researchers and students can test, validate and develop technologies and products. The facilities differ in the TRLs they cover and the technologies with which they deal. Moreover, some are in the planning stage or under construction (hatched boxes), while others are open for business (grey boxes).

On the Danish side of Greater Copenhagen, promotion of framework conditions for the Biosolutions industry has been a business policy priority of the Biosolutions lighthouse project (see p. 13). The project is funded with EUR 8 million from the Board of Business Development. A key aim is to build an open and coherent infrastructure in which companies can test and scale up solutions and products using bio-fermentation and refinery technologies. A total of seven test facilities located around Zealand are supported.

On the Swedish side of Greater Copenhagen, most test facilities focus on waste technologies, including those handling different types of sewage water and bio waste. Lund University hosts the MAX IV and ESS Laboratory, where it is possible to study a broad range of materials and processes in detail by means of synchrotron X-rays, and the private company Uniper is hoping to transform the former nuclear power plant, Barsebäck, into a testbed for clean energy solutions.

Access to facilities varies. Facilities in universities normally prioritise researchers over businesses, and indeed some (e.g. Open BioLab) make collaboration with researchers or students a precondition of company access. Other facilities located at Research and Technology Organisations (RTOs) (e.g. the Danish Technological Institute (TI) Biosolutions Technology Center) are open to all. Private companies usually do not offer others access to their own facilities.

Selected labs and facilities in Greater Copenhagen



Source: IRIS Group.

Danish part of Greater Copenhagen

- **DTU Kemiteknik - Pilot Plant** specialises in the processes of fermentation and the conversion of biomass into high value products. It concentrates on the progression from laboratory scale to pilot scale experimental processes, with emphasis on industrial practice.
- **TI - Biosolutions Technology Center** is a pilot scale bio-fermentation facility that is integrated with the existing, food-approved biorefinery plant. It houses state-of-the-art fermentation tanks on a 1L, 10L, 200L and 2,000L scale. The bio-fermentation facility is under construction.
- **FermHub** is a complete, state-of-the-art industrial bio-fermentation facility for the production of new foods by fermentation. It has a 5,000L fermentation tank, and some minor tanks are in the production line. The facility is under construction.
- **21st Bio** is a private company helping bio-industrial businesses from all over the world to scale up from molecular innovation to large-scale production. Its focus areas include the production of proteins and peptides for use in food, materials and agriculture. The company has bio-fermentation test facilities (at an early stage), and facilities for scaling to an industrial level are under construction.
- **Open BioLab** at Roskilde University is a laboratory offering SMEs access to biochemical equipment at laboratory scale that can be used to characterise the functionality of plant-based food ingredients and to develop data-driven process control. Companies access facilities through collaborative projects with researchers and students.
- **DaniaBioProcess**, operating under the auspices of the private company SiccaDania, will focus on the biorefining of unprocessed agricultural crops, including design and testing of plant-based food ingredient production. The facility is on the drawing board.
- **Baltic Plant Solution** is a plant for upscaling of products and technologies set up by a circle of public and private partners. The plant enables companies to scale up to 500

tonnes of production. The plan is that it will refine both dry and wet biomasses, residual products, side-streams from fermentation, etc. The facility is on the drawing board.

Swedish part of Greater Copenhagen

- **RecoLab** is a sewage treatment plant facilitating and promoting energy-efficient and circular sanitation processes. Using a new system, the plant extracts resources from the sewage water more efficiently. Thus, it recycles three times as much phosphorus and seven times as much nitrogen as conventional plants do. The plant recently opened to industry, researchers and students.
- **Vera Park** – Vera Park is a waste facility for the testing of new solutions to waste management and recycling. The park provides a physical testbed on which researchers and companies can try out their ideas. It aims to optimise resource efficiency by generating circular flows.
- **Krinova Incubator and Science Park (WISA testbed)** focuses on water innovation, including sewage treatment plants, water treatment plants, port facilities and surface water environments for experimenting and testing. Access to facilities is offered through close collaboration with the local municipalities.
- **MAX IV** is a laboratory providing high-quality X-ray light for research in materials and life sciences. The laboratory uses an accelerator complex and is the first realisation of a fourth-generation light source in the world. MAX IV can be accessed by academics and industry through user access programmes.
- **Barsebäck Clean Energy Park** is a hub for the development of future solutions in energy and industry (e.g. solar cells, battery storage, hydrogen production through electrolysers, etc.). It has facilities for development and practical testing. There is currently no final decision of the future use of the area, and the facility is on the drawing board.

Investments – R&D and Venture Capital

R&D and venture capital investments are crucial to companies developing solutions and products in biotech and PtX. As these are research-intensive fields, large investments are often needed to mature, scale and commercialise the technologies and products.

High levels of R&D investments

Generally speaking, Greater Copenhagen has high levels of R&D investment in comparison with similar metropolitan areas. In 2019, a total of EUR 8.5 billion was invested in R&D across industry, the universities and the public sector, as shown in the figure (upper right). Greater Copenhagen invests more funds in R&D than other European metropolitan areas such as Stockholm, Berlin and Helsinki.

Industry accounts for a large part of the R&D investments in Greater Copenhagen (around EUR 6 billion). This is due, not least, to the existence of a significant and research-intensive life science industry on both sides of Oresund, which also includes Biosolutions. However, several billion euros are also invested in the R&D conducted in the universities. Rates of investment are particularly high in the Capital Region and Region Skåne.

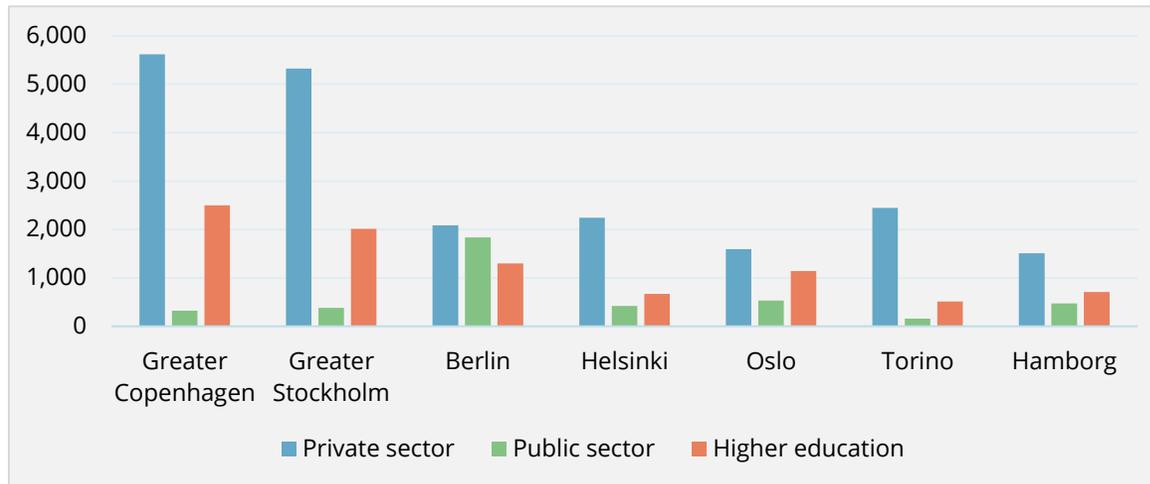
Increasing venture capital investments in sustainability

While Greater Copenhagen performs well in terms of R&D investment, the region lags behind in its ability to attract venture capital in comparison with similar metropolitan areas. Recent analyses show that the Capital Region in Greater Copenhagen attracted barely EUR 700 million in venture capital in 2022, whereas Stockholm attracted around EUR 3.8 billion the same year.

Although Greater Copenhagen is not pre-eminent in attracting venture capital, investments in the region have generally increased over the last few years. This applies particularly to investment in companies with sustainable business models and products, as shown in the figure (lower right). In 2022, almost EUR 206 million was invested in green companies (Denmark's Export & Investment Fund, 2022).

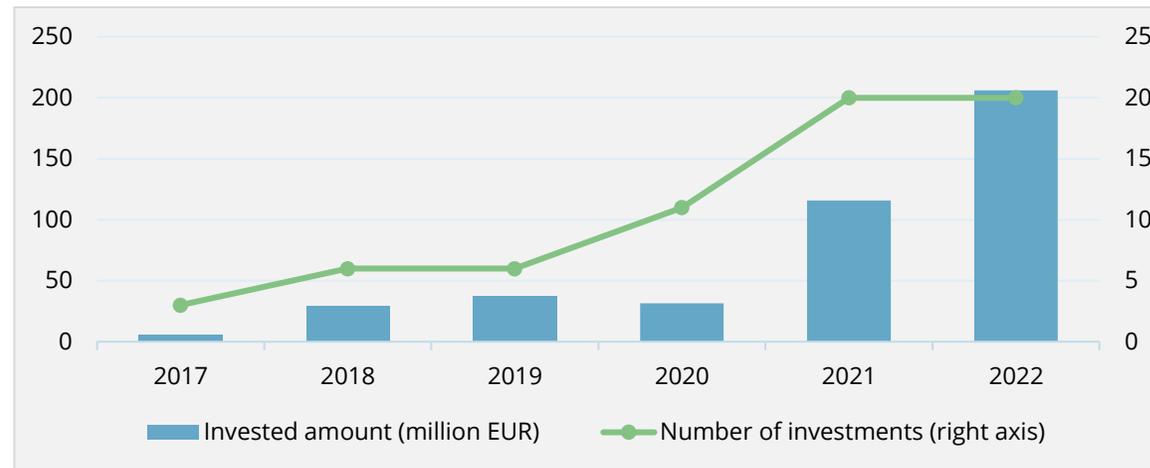
The improvement has been supported by government investments. Both Denmark and Sweden have public venture capital funds focusing on green investments. The Danish Green Investment Fund (part of the country's Investment Fund) manages EUR 1 billion, whereas the Swedish Green Tech Fund (part of ALMI) manages EUR 65 million.

Research expenditure by sector, 2019 (million EUR)



Source: Greater Copenhagen based on Eurostat.

VC investments in companies with green business models or products



Source: Denmark's Export and Investment Fund.

Note: All investments from 2017-2022 have been reviewed in order to assess whether the individual companies have a green business model or a green product. Green due diligence or life-cycle analyses have not been carried out on the individual companies. Therefore, figures must be interpreted with some caution.

4. Challenges and Policy Recommendations

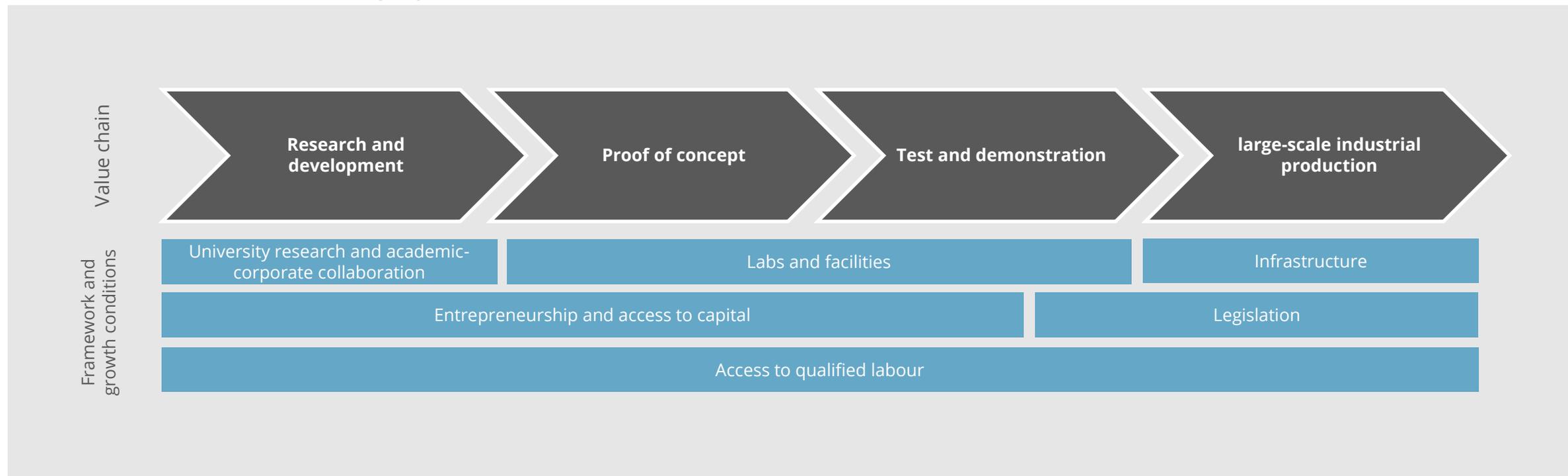


Framework and Growth Conditions

This chapter considers the framework conditions required for the development and production of Biosolutions and PtX in Kalundborg and Greater Copenhagen. The conditions span the entire technology and product value chain – from early research and development, through proof of concept, and test and demonstration, to large-scale industrial production. Some framework conditions are of particular importance at one (or more than one) of these stages of the value chain, and others are important at all stages, as illustrated below.

On basis of previous analysis and the interviews conducted for this study, six groups of framework conditions, illustrated by the blue bars below, were identified. These include top tier university research and academic-corporate collaborations, access to state-of-the-art labs and facilities, a vibrant community for entrepreneurship and access to capital, legislation that is fit for purpose, access to qualified labour, and finally infrastructure to support large-scale production. On the following pages, the significance of, and main barriers affecting, each of the six groups of framework conditions are discussed. In each case, a number of policy recommendations aiming to address the barriers and strengthen the entire Biosolutions and PtX ecosystem are then proposed.

Framework conditions from a value chain perspective



University Research and Academic-Corporate Collaboration

Biosolutions and PtX are knowledge-based, research-intensive fields. A thriving ecosystem for them is therefore characterised by top tier university research and well-established ties between stakeholders at universities and linked industries. Collaboration between universities and Biosolutions and PtX companies is vital for technology development.

Greater Copenhagen is home to several universities and companies that conduct world leading research and innovation connected with Biosolutions and PtX. Recent analysis reveals that Danish universities and companies accounted for 2.2% of all biotechnology patents taken out globally (ATV, 2020). For decades Danish research environments have been engaged in electrolysis and synthesis technologies relevant to PtX (IRIS Group, 2019a).

As explained on page 26, Greater Copenhagen presently enjoys relatively high levels of R&D investment. However, previous analyses have indicated that in Denmark grants towards, and investments in, Biosolutions (IRIS Group, 2021a) and energy technology (IRIS Group, 2019b) are balanced towards application-oriented research rather than basic research.

Generally, university researchers in the region are well-informed about competencies and activities at other relevant university departments, and occasionally they participate in joint research projects (Sustainable Business Hub, 2021). While ties between the leading research environments within universities, and between universities and large corporates, are well-established, our interviews suggested that framework conditions for collaborative projects between universities and small companies, and between startups and large corporates, are not yet optimal. Projects of this kind require significant administration, given their size, and in them considerable time is devoted to building networks and writing applications. Equally, small companies sometimes hesitate before collaborating with large corporates, particularly on research projects, as they fear losing control of their innovative solutions. These findings from the interviews align with the results of previous studies (IRIS Group, 2021a; Sustainable Business Hub, 2021).

Good framework conditions for collaboration are important, because the ability to form and facilitate complex partnerships across academia, innovative startups, and public and private companies, is expected to be a significant competitive parameter in the next 3-5 years (IRIS Group 2023).

Recommendations

To sustain a leading Biosolutions hub in Greater Copenhagen and mature PtX technologies in Southern Scandinavia, support for basic research and academic-corporate collaboration are essential. Some interviewees stressed that a hub to facilitate increased cross-border collaboration and new partnerships between researchers and industry is needed. Others felt more information about, and discussion of, the focus and content of future collaborations would be required before a hub is established. Some steps have been taken in this general direction with the establishment of The Nordic Bio Solution Hub, but the initiative is still very young and does not include PtX. We recommend that:

- An analysis is scoped to obtain an updated picture of research funding opportunities and conditions for engagement in international research projects related to green solutions, including Biosolutions and PtX.
- All partners within the Nordic Bio Solution Hub continue efforts to address common challenges, including how to support small companies' participation in collaborative projects with researchers and large corporates (e.g. with matchmaking and confidentiality agreements). And Swedish partners in the Nordic Bio Solution Hub continue efforts to identify relevant stakeholders across industry, academia and authorities in order to specify their interest and willingness to commit to an extended cross-border partnership.
- A Nordic PtX hub is established to ensure that innovation potential and cooperation across stakeholders active in the PtX sector are realised. Many PtX projects are currently being developed. Sharing of early insights and coordination of infrastructure development will be essential as PtX projects move from demonstration to large-scale facilities.

Labs and Facilities

Access to laboratories and facilities for test, demonstration and scaling is vital for Biosolutions companies aiming to bring new technologies to the market. This is because companies must be able to manufacture large quantities of their products, which must be of uniform quality, cheaply if they are to demonstrate an attractive business case.

The industrial symbiosis in Kalundborg is dominated by large, high-profile companies like Novo Nordisk and Novozymes. Naturally, such companies have their own labs and facilities. These are not open to startups, but one interviewee from the industry noted that some private facilities could potentially be opened up to other companies in the future.

Many good ideas for Biosolutions are born in laboratories that are often situated in universities, and young startups rarely have their own labs and facilities for scaling, meaning that they are usually dependent on open facilities where they can demonstrate and scale their solutions. Thus, such open labs and facilities are vital to the entire value chain in bio-innovation as well as the commercialisation of research (IRIS Group, 2021b; Sustainable Business Hub, 2021).

The equipment needed for Biosolutions testing and scaling is quite uniform: primarily, it consists of tanks in different volumes for fermentation and refinement. But access to competent staff who can advise companies on scaling, purification and the correct use of the equipment, is essential as well (ibid.).

Previous studies have revealed that an open infrastructure for the testing and scaling of technologies in both Denmark and Southern Sweden is lacking (ibid.). This is especially true of the last levels of the TRL scale, where technologies have become more mature but are not quite ready for commercialisation yet (see also page 24). An unwelcome upshot of this is that some promising technologies never move beyond the laboratory stage. In other cases, companies must seek open scaling facilities abroad, with the risk that they will be significantly delayed in comparison with their foreign competitors.

Recommendations

In the past few years, challenges for startups which lack access to open labs and facilities have received more attention. On the Danish side of Greater Copenhagen, these challenges have been addressed under the auspices of Biosolutions Zealand Lighthouse, which – among other things – supports the establishment of open facilities for testing, demonstration and scaling, and which aims to cover the whole value chain from research to commercialisation. In addition, facilities such as the RECO lab on the Swedish side of Greater Copenhagen have opened recently. All facilities target companies, researchers and students, and most – but not all – are ready to receive customers. We know that the target group's knowledge of these relatively new facilities is currently limited. Hence, we recommend that:

- Biosolutions Zealand Lighthouse works to raise substantial additional funding in order to prepare relevant facilities to receive customers.
- Greater Copenhagen diffuses awareness of the facilities and their applications – both on the Danish and Swedish sides of Oresund. Developing a digital map might be relevant.
- DI Bio scope a study to investigate how subsidy schemes for companies that wish to use the facilities can be developed.
- Knowledge Hub Zealand explores opportunities to open up (at least some of) the facilities located in large companies in, for instance, Kalundborg. Open facilities would not only benefit startups. Large companies can benefit too by cooperating with innovative entrepreneurs. Alfa Laval Innovation House in Copenhagen can serve as inspiration.

Entrepreneurship and Access to Capital

The development of Biosolutions and the PtX sector is not only driven by large corporates. Small innovative startups are key to it, too. It is important to have a layer of research-based entrepreneurs who focus on maturing, testing and scaling ideas and technologies that originate from research and laboratory work at the universities.

The startup scene for Biosolutions and PtX is currently small. In 2021, the Biosolutions sector comprised around 130 companies, of which 35 were less than five years old (IRIS Group, 2021a).

Greater Copenhagen is home to several startup hubs, with Skylab at DTU offering the most suitable environment for biotech entrepreneurs.

However, no dedicated accelerator programmes for Biosolutions startups are being offered, and currently there is no physical startup hub in the innovation district of Kalundborg. The industrial symbiosis is dominated by large companies because substantial investment is required to integrate physically in the symbiosis. Competition for qualified labour is tough, with high wage levels offered by large corporates. Nevertheless, if project partners in PtX Cluster Zealand like DynElectro and G2B Biosolutions decide to establish

themselves permanently in the symbiosis, it will be enriched with innovative startups.

As regards capital, soft funding programmes with relevance to Biosolutions and PtX startups do exist in Greater Copenhagen. However, according to the startups interviewed for this study, the application process for soft funding is very time consuming given the size of the funding on offer. Biosolutions and PtX are research intensive fields in which there is a long lead time to market.

Though VC investments in companies with sustainable business models and products have increased in recent years, Greater Copenhagen continues to lag behind other metropolitan areas. Boosting foreign investments in the region will be essential if we are to support startups and scaleups, and ensure they stay in Greater Copenhagen.

Finally, the European Commission's effort to create a common classification system for sustainable economic activities – the so-called “EU taxonomy” – is believed to direct more investments towards sustainable projects and activities if the technical screening criteria are defined accordingly.

Recommendations

The enhancement of the startup environment in Kalundborg has received less attention than other tasks, such as attracting educational programmes. However, some efforts have been made: for instance, startups and SMEs were matched with knowledge institutions in order to solve specific innovation challenges in the project “Change Zealand”. Potentially, the startup environment in the innovation district around Kalundborg could be developed in various ways. It is clear, however, that a dedicated startup hub would be capable of attracting startups spun out from research environments – either nationally or internationally – and help them to integrate in the symbiosis. We recommend that:

- A dedicated Biosolutions accelerator programme is established. The headquarters could be located in Kalundborg in a collaborative model involving universities in the region and offering an open door to startups not located in Kalundborg. The accelerator could offer advice on fund raising and legal issues, introduce startups to labs and facilities, and help Biosolutions entrepreneurs to become part of a broader professional sector network. In addition, scouting arrangements could be made in order to identify promising startups in leading research environments – in Greater Copenhagen and abroad – that may be interested in becoming part of the biotech hub in Kalundborg.
- Greater Copenhagen leads a joint effort to attract foreign VC to the Greater Copenhagen region, with Kalundborg as an industrial symbiosis showcase.
- The confederation of Danish Industry unifies trade organisations in European member states with large biosolution sectors in a common effort to ensure that the technical screening criteria for the EU taxonomy will classify the production of Biosolutions as a sustainable economic activity.

Legislation

Scaling and commercialising Biosolutions can be challenging if the legislation and other regulation pertaining to it is not fit for new technologies and processes. Biosolutions are fundamentally different from conventional products, but in some respects they fall under the same regulatory framework.

Modern gene technology ensures that Biosolutions have huge potential. We can now modify the genetic make-up of living cells and organisms artificially, introducing valuable new features. Crops can be modified to give them resistance to disease, or insects or drought. Plants can be fine-tuned for better quality or nutritional value, or increased yield. Current EU legislation prescribes that all GMOs must be approved before they can be used in the EU. A revision of the GMO legislation is under way, but the EU Commission's preparatory work on easing the legislation currently covers plants only, not animals and microorganisms.

Another issue arises over prolonged product approval processes in the EU, sometimes lasting seven years (IRIS Group, 2022). As a result of this, many Biosolutions are launched in other regions of the world before they reach European consumers. New biobased food ingredients are challenged if they are defined as “novel foods”. In the food industry, new

Biosolutions are constantly being developed, and companies are obliged to assess whether a new product is a novel food. The assessment requires expertise on the novel food regulation that startups with limited legal capacity often lack. When a product is characterised as novel food – as many Biosolutions are – the European Food Safety Authority (EFSA) steps in to assess potential risks of consuming it. Long and costly application procedures are involved here.

Lengthy approval processes have also been an issue for companies developing pest Biosolutions for agriculture. For many years, biological alternatives to chemical pesticides were not recognised as a separate regulatory category and followed the same set of data requirements and approval processes as the chemical pesticides. Recently, evaluation criteria and requirements for applicants have been adjusted, making them more fit-for-purpose in the assessment of complex biological entities. Denmark and the Netherlands were first to introduce assessment criteria specifically based on biological properties of microorganisms – a shift away from the criteria developed to approve chemical products. The registration of biocontrol solutions in the EU remains is also complicated by a dual process: the EFSA authorises active substances, while products are authorised nationally.

Recommendations

If Biosolutions companies are to succeed in global competition, they must be able to use the latest technologies and obtain market access rapidly and safely. We recommend that:

- Government stakeholders work to ensure that the EU Commission actively supports the collection of information on microorganism use. Currently, the Commission assessment is that there is insufficient knowledge to initiate preparatory work on revising the GMO legislation on animals and microorganisms. It is therefore crucial that the Commission collects information on, for example, the safety of releasing microorganisms, as historically it has taken a long time for this type of EU legislation to be revised.
- The Danish Ministry of Food, Agriculture and Fisheries – with the support of ministries in other EU countries – put political pressure on the EU Commission and EFSA to rethink the novel food regulation and approval procedure – of course, without compromising food safety. Inspiration here could be found in the so-called “simplified procedure” applying to traditional foods from countries outside the EU and the US’s categorisation of food ingredients as Generally Recognized As Safe (GRAS). In the latter, ingredients do not need to undergo the usual Food and Drug Administration (FDA) approval procedure if a qualified team of experts has assessed them as safe to use.
- Government stakeholders work to ensure that a fast-track system for low risk/minor use biological solutions is implemented at EU level, both in the approval of active substances and in product authorisation. The fast-track system should include prior review by experienced member states, adaption of the Danish/Dutch evaluation manual to incorporate new data requirements adapted to biologicals, and clear guidance for applicants.

Access to Qualified Labour

Biosolutions and PtX companies depend on a highly skilled workforce. Engineers and other candidates with degrees in biotechnology, chemistry, sustainable energy, food science, agriculture and allied disciplines carry out R&D and also work in operational control and quality assessment. In addition, the companies need skilled electricians, and process and industry operators, capable of running and maintaining their production sites. And they require external local craftsmen specialised in installing and maintaining the equipment (e.g. large fermenters) at the production plants.

It is a strength of Greater Copenhagen that it offers companies a highly educated workforce, a rather large share of which (almost 4%) currently works in R&D – this is higher than in other metropolitan areas (Greater Copenhagen, 2023). Interestingly, previous analyses have found that Biosolutions companies generally believe that engineers from Danish universities are highly qualified (IRIS Group, 2021a).

Biosolutions and PtX companies attract international employees. The companies often have an international mindset and are oriented towards a global market, and this is

reflected in their employees' different cultural backgrounds (IRIS Group, 2021a).

When it comes to recruiting qualified labour, differences between the capital area and other parts of Greater Copenhagen are apparent. Companies located in the capital area seem to have fewer problems attracting and retaining qualified employees. Those in peripheral areas of the region, by contrast, are more challenged in these respects. Not the least affected are smaller companies, which may also find it difficult to compete with salary levels offered by larger competitors (ibid.). These challenges also exist in Kalundborg, even though the industrial symbiosis is dominated by big companies.

Recommendations

In the past seven years, much has been done to enhance companies' access to qualified labour in the local innovation district of Kalundborg. Knowledge Hub Zealand was established in 2016. The main aim was to attract higher education providers and students to the area, thereby expanding the pool of qualified labour locally. Today, Kalundborg is home to several educational programmes (e.g. in biotechnology, bioanalysis, mechanical technology and engineering) and more are on the way in the years to come (see page 16). In the growing educational environment in Kalundborg, raising awareness of new educational programmes and recruiting and retaining students after enrolment are key tasks. Hence, we recommend that:

- Additional funding is raised for ongoing awareness-raising activities targeted at young people and adults (Danish and international) who might be interested in tech-related educational courses at Kalundborg Campus.
- Activities are set up promoting the retention of Danish and international students in the local area after graduation.
- Efforts are made to attract more international employees – e.g. by drawing on resources available from the EU-funded project "Competences for a Green Denmark" under the leadership of Copenhagen Capacity.

Infrastructure

When they are manufactured on an industrial scale, Biosolutions, and especially PtX products, require a dedicated infrastructure capable of supplying large amounts of energy, water and other materials.

The industrial symbiosis in Kalundborg is an energy intensive unit already. Adding PtX production to the area would significantly increase energy needs. Renewable energy can be brought in from areas with a production surplus (e.g. the southern part of Zealand). It could also be produced closer to the site. Both options will require large infrastructure investments in the electricity transmission network, or new wind turbines or solar photovoltaic (PV) structures.

In 2023, grid companies are expected to be allowed to differentiate consumption tariffs geographically for large electricity consumers connected to the grid. The aim is to create a financial incentive for PtX facilities to locate near an electricity production site. The differentiated consumption tariffs will probably make PtX production in Kalundborg more expensive if a local production site is not established. On the other hand, if a production

site is established, a commercially owned direct line (i.e. an electricity connection between an electricity producer and an electricity consumer) could improve the PtX business case.

Expansion of water supply and treatment facilities is essential too, as biomanufacturing and PtX are water intensive. Ways of using surface water, impaired groundwater or treated wastewater effluent will be need to be developed in order to ensure there is potable groundwater that is safe for drinking purposes.

Finally, large-scale PtX production would require new infrastructure systems for transportation and the storage of hydrogen and carbon to be considered. Currently, a Danish-German hydrogen pipeline is on the table, and six Danish cities (i.e. Copenhagen, Aalborg, Aarhus, Esbjerg, Fredericia, Odense) have been identified as carbon clusters and asked to analyse opportunities, needs and costs for local carbon infrastructures.

Recommendations

Large infrastructure investments will be made in the coming decades to support the transition from a fossil-based economy to a sustainable one. In this evolution there are still many unknowns, and we therefore recommend that:

- Future energy demand in Kalundborg is properly assessed, including for scenarios with 1-2 GW PtX production. The analysis should cover opportunities to establish new energy production sites near Kalundborg (including, for example, offshore wind turbines). It should also consider potential direct lines between production and consumption facilities, as well as the impact of geographically differentiated consumption tariffs. More knowledge is required on water supply and the need to expand water treatment facilities, as well as on how to utilise surplus heat in the district heating system and, potentially, distribute it to Holbæk, Slagelse and Sorø.
- Kalundborg Symbiosis strives to transform Kalundborg into a carbon cluster like Copenhagen, Aalborg, Aarhus, Esbjerg, Fredericia, and Odense. Kalundborg is a clear-cut case for carbon capture because biogenic carbon can be sourced from the the biotech production sites, and from the biogas and power plants in the Kalundborg Symbiosis. Kalundborg and the surrounding area are also well-placed to handle the transport and storage of carbon. Kalundborg harbour can serve as a hub for carbon transportation, and two sites close to Kalundborg (Havnsø and Stenlille) have been highlighted as ideal locations for carbon storage.

Biotech accelerator in Delft, Holland

Planet B.io is a scaleup ecosystem focused on industrial biotechnology. It is located at the Biotech Campus Delft, close to the technical university, TU Delft. Currently, it is one of the only accelerators in Europe to focus exclusively on industrial biotech.

Planet B.io offers a wide range of services. Among other things, these include:

- 3,000 m² office space and common areas.
- Networks for technical experts at the Biotechnology Center on campus, which houses more than 400 scientists, as well as the rest of TU Delft. Planet B.io regularly hosts events at which members of the community can meet and network.
- Access to the Bio Process Pilot Facility where pilot scale equipment and in-house expertise is available to help companies progress from lab to industrial scale production.
- Support in finding financing, including networks extending to biotech investment funds and business angels as well as a voucher system established in collaboration with the Province of South Holland.
- Access to talent through collaborations with educational institutions at different levels.
- General guidance on how to start and run a business, including access to commercial and legal advice and information on other relevant matters.

Planet B.io cost around EUR 3.5 million to set up. The funds came primarily from the private company DSM, the Municipality of Delft and the Province of South Holland.

Scaleup facility in Gent, Belgium

Bio Base Europe Pilot Plant (BBEPP) is an open demonstration facility established in Gent in 2008. It functions as a one stop shop enabling the conversion of renewable feedstocks into biochemicals, biomaterials, biofuels and other bioproducts using technologies such as biomass pre-treatment, biocatalysis, (gas) fermentation, green chemistry and product recovery and purification.

BBEP offers three kinds of service:

- *Scale up* by a factor 10, 100, 1,000 or 10,000, which transforms lab scale processes into industrially viable processes.
- *Process development*, in which processes are closely reviewed in order to increase productivity, efficiency and sustainability and decrease overall production costs.
- *Custom manufacturing*. Where a biobased process has attained its production targets and is ready to enter the market, BBEPP offers to manufacture the product to allow customers to postpone investment in full scale industrial production.

BBEPP has been particularly successful in shortening the process from laboratory to production and making that progression less risky for smaller companies and startups. It also functions as a stamp of approval, encouraging private investment and making it easier to raise venture capital.

The set up cost of BBEPP was approximately EUR 13 million. This came from the EU, and the Belgian and Dutch authorities. Further investments of EUR 30-40 million were then made to reach current capacity.

Fast track policies in Europe

To promote the transition to more sustainable agriculture, both France and the Netherlands have established fast-track schemes for approvals of microbiological plant protection products.

Both schemes aim to accelerate the products' case processing and to extend the selection and use of biological products on the market.

Although their overall goals are similar, there are also some differences between the schemes.

In France, the ambition is to cut case processing time for microbiological products to 6-8 months (it is 12 months for chemical products). To realise this ambition the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) has recruited significantly more case workers. It also allows continuous receipt of applications (specific times must be booked for those relating to chemical products) for which it offers reduced processing fees.

In the Netherlands, the Environmental Agency (Ctbg) has introduced several measures to secure a smoother process. First, applicants are offered meetings with Ctbg prior to their application at which documentation requirements, costs and the entire process is clarified. Second, a fixed amount of time is allocated to case work on biological products. In practice, this means these applications are prioritised over chemical products. And third, a team of specialised caseworkers has been established and expanded over the years.

These fast-track schemes have led to increased interest in microbiological plant protection products. In France and the Netherlands, the numbers of applicants from other European countries have risen.

Appendices



Appendix A: List of Interviewees

- Anette Birck, Director, Helix Lab
- Anna Haldrup, Head of Department, Department of Food Science, University of Copenhagen
- Birte Fønnesbech Vogel, Ph.D. Civil Engineering, The Danish Environmental Protection Agency
- Christian Beenfeldt, Project Director, Knowledge Hub Zealand
- David Egede Fich, Senior Lead Business Developer, Ørsted
- Flemming Dengsø, Analyst, Greater Copenhagen
- Henrik Busch-Larsen, Founder and CEO, Algiecel
- Håkan Rosqvist, Managing Director, Sustainable Business Hub, Malmö
- Jens Sørvik, Regional Development Environment and Health, Region Skåne
- Martin Hartvig, Senior Engineer, Energinet
- Michael Elleskov, Senior Fermentation Engineer, Unibio
- Nicolai Vædele, Committed Director, Greater Copenhagen
- Nicolai Zarganis, Head of Corporate Strategy, Andel
- Per Falholt, CSO, 21st BIO
- Per Møller, Senior Symbiosis Developer, Kalundborg Symbiosis
- Per Persson, Senior Advisor, Lunds Municipality
- Preben Thisgaard, Senior Project Chief, Kalundborg Utility
- Carina Johnsson, Development Manager, Region Skåne
- Seyed Soheil Mansouri, Associate Professor, Chemical Engineering, Technical University of Denmark
- Sofi Eriksson, Advisor, Greater Copenhagen
- Steen Skærbæk, Senior Director, Novozymes
- Svend Christensen, Head of Department, Department of Plant and Environmental Sciences, University of Copenhagen
- Søren Højgaard, Managing Director, Dynelectro

Appendix B: Literature

- ATV (2020): "Verdens førende tech-regioner - Danmarks styrkepositioner i et globalt perspektiv"
- Copenhagen Economics (2022): "The Potentials of Bio Solutions - Climate and sustainability potentials, barriers to growth, and Danish strongholds"
- Danish Ministry of Climate, Energy and Utilities (2021): "The Government's Strategy for Power-to-X"
- Denmark's Export & Investment Fund (2022): Figures from presentation in Greater Copenhagen (March 2023).
- Det Nationale Bioøkonomipanel (2022): "Bioressourcer til grøn omstilling".
- Energinet (2022a): "Langsigtede udviklingsbehov i elnettet"
- Energinet (2022b): "Systemperspektivanalyse 2022 - Udviklingsveje mod fremtidens robuste energisystem"
- Energistyrelsen (2021a): "Analyse af geografisk differentierede forbrugstariffer og direkte linjer"
- Energistyrelsen (2021b): "Muligheder og udfordringer ved indpasning af storskala PtX i det danske elsystem"
- Greater Copenhagen (2022): "Greater Copenhagen Green"
- Greater Copenhagen (2023): "Betingelser for fremtidens vækst – en sammenligning af Greater Copenhagen med andre storbyregioner"
- HBS Economics (2021): "CO₂e-reduktionspotentiallet fra biosolutions i 2030 - Analyse for Dansk Erhverv"
- IRENA (2020): "Green Hydrogen Cost Reduction: Scaling up electrolyzers to meet the 1.5° C climate goal"
- IRIS Group (2019a): "Analyse af energiteknologiklyngen"
- IRIS Group (2019b): "Analyse af statens indsats for forskning, udvikling og demonstration på energiområdet"
- IRIS Group (2021a): "Biosolutions i Danmark"
- IRIS Group (2021b): "The Plant Biologicals Cluster in Southern Scandinavia"
- IRIS Group (2022): "Regulatoriske barrierer for udvikling af biosolutions"
- IRIS Group (2023): "Analyse af megatrends og deres betydning for danske SMV'er"
- Katz, Bruce & Wagner, Julie (2014): "The Rise of Innovation Districts: A New Geography of Innovation in America"
- McKinsey & Company (2023): "Europe's Bio Revolution: Biological Innovations for complex problems"
- McKinsey Global Institute (2020): "The Bio Revolution - Innovations transforming economies, societies, and our lives"
- Ramboll (2022): "2 myths and an open question about water and Power-to-X"
- Sustainable Business Hub (2021): "Underlagsrapport - Kartlægning och förankringsdialog av Bioteknikområdet i Skåne"
- York University (2022): "Ecological Footprint Initiative & Global Footprint Network"

Appendix C: Bio Actors in Greater Copenhagen

| Category | Name | Purpose description |
|---|---|---|
| Clusters, think tanks, industry organisations | Biosolutions Zealand | State-appointed business hub (i.e. "hard" activities) based in Region Zealand. Supports the development of new test and demonstration facilities with public funds. |
| | Food & Bio Cluster | State-appointed cluster (i.e. "soft" activities) for Denmark. Strengthens innovation and cooperation across the value chain for food and Biosolutions through 1) networks, 2) business development, 3) innovation, and 4) financing. |
| | Food Nation Denmark | Public-private partnership showcasing Danish technology and solutions within the food sector (including yellow biotech) to foreign partners/investors/customers. |
| | Knowledge Hub Zealand | Regional, self-appointed cluster. A partnership created in 2016 to support knowledge, education and development in the Region Zealand – focusing particularly on the development journey within biotech. |
| | Tænketanken Frej | Think tank driven primarily by young people with a focus on agriculture/circular economy. |
| Financing | Novo Nordisk Foundation | Business-driven foundation with two purposes: 1) a stable foundation for the business activities driven by companies in the Novo Group, and 2) support for scientific, humanitarian and social purposes. |
| | Innovation Fund Denmark | Fund that aims to create favourable conditions for the country's entrepreneurs, researchers and companies, so that they can develop innovative and viable solutions to society's challenges. |
| | UDP's (GUDP, EUDP, MUDP) | Schemes that provide support for projects in various industries that aim to create new and improved technologies, and to apply these technologies. |
| | AgriFoodTure | A partnership bringing together universities, knowledge and innovation institutions, SMEs, large national and international companies, civil society actors, and associated authorities, around a common vision for Danish agriculture and food production. |
| | Horizon Europe | A European programme promoting and funding research and innovation activities that address major societal challenges and contribute to the EU's economic competitiveness. |
| Labs, facilities, accelerators | 21.st BIO | Production and test facility (fermentation) supported by Fyrtårnet – currently under construction. |
| | Baltic Plant Solutions | Scaling facility (biorefinery) supported by Fyrtårnet - currently on the drawing board at Nordic Sugar. |
| | Dania Bio Process | Demonstration facility (biorefinery) supported by Fyrtårnet - currently on the drawing board at SiccaDania. |
| | FermHub | Demonstration facility (fermentation) supported by Fyrtårnet – currently under construction. |
| | Open Bio Lab | Laboratory (biorefinery) supported by Fyrtårnet. |
| | Bio Innovation Institute | Accelerator programme for biotech entrepreneurs funded by Novo Nordisk Foundation. |
| Research and education | University of Copenhagen | Educational institution conducting biotechnology research in food and agriculture in its Department of Plant and Environmental Science and Department of Food Science, with research areas including food microbiology, fermentation, plant-based foods and plant protection. |
| | Technical University of Denmark | Educational institution hosting several divisions undertaking research of relevance to the Biosolutions and PtX sector. |
| | Roskilde University | Educational institution with a research group focusing on environmental dynamics, including biological production based on micro algae. |
| | University College Absalon | Educational institution with research environments focusing on the development of healthy and sustainable foods. |
| | Lund University | Educational institution with several departments engaged in research of relevance to biobased products and processes, with a focus on areas such as bioprocess technology, microbial catalysis and biomass fractionation. |
| | Swedish University of Agricultural Sciences | Educational institution conducting biotechnology research into applied in agriculture, including plant breeding, plant protection biology, and biosystems and technology. |
| | Danish Technological Institute | Institute developing, applying, and disseminating research and technology-based knowledge, including offering access to 70 test, demo and development facilities. Approved as a Research and Technology Center, which among other things makes it possible to apply for resulting contract funds. |

IRIS GROUP

CHRISTIANS BRYGGE 28, 1st FLOOR | DK-1559 COPENHAGEN V

IRISGROUP@IRISGROUP.DK | WWW.IRISGROUP.DK