Cultivating plants in a controlled environment

Interview with Nico Domurath

People at Fraunhofer IKTS are driven by the aim to develop holistic economical and sustainable systems as well as services for practical applications. They work together across various disciplines to gain insight into the complex questions of our time, and drive innovation.

Agricultural expert Nico Domurath is one of them. His technical center in Dresden-Gruna is not hard to find. Just follow the violet light emitted from the panes of his lab door. It comes from compact, glazed test beds housing plants on several levels. The scent of basil lingers in the room. This indoor farm at the ceramics institute is a prime example of interdisciplinary cooperation.

Mr. Domurath, what is the research question you intend to solve as a horticulturist at an institute dedicated to technical ceramics?

My focus is on growing crops under controlled conditions, also known as **CEA, controlled environment agriculture**. This mainly includes greenhouse horticulture and vertical farming. The industry is currently experiencing an increasing dynamic growth. In view of the UN's sustainability goals, we aim for a bio-based economy that uses natural material cycles while protecting natural resources and meeting the needs of a growing world population. If it is eight billion people today, it will be more than ten billion people by 2050, which will have to be supplied with food and raw materials – 80 % of them in large cities. We consider CEA systems to be part of the technical infrastructure that underpins food production and the bioeconomy. They provide optimal growth conditions for plants or organisms, for example to ensure a healthy diet: In greenhouses or vertical farms, any climate in the world can be created indoors, regardless of the season and location. This promises year-round yields in consistent quality and quantity. For instance, tomatoes, lettuce and herbs, or protein-rich vegetables, no longer need to be harvested before they are ripe and then transported to our supermarkets for days across thousands of miles from the dry south or from overseas. This reduces emissions as well as the virtual water and land consumption. All this means that plant growing in a controlled environment is a major lever when it comes to the ecological footprint and the decentralized supply of demand for food and the bioeconomy. However, we know from analyses: A lot of development is needed for the CEA concept to become profitable. We aim to solve the urgent challenges with our robust ceramic and diagnostic components and technologies.

How can the efficiency of cultivation setups in a controlled environment be optimized? What is your approach?

"We think that the state of the art in crop cultivation in controlled environments can be raised to a new level with an integrated, interdisciplinary systems approach."

At Fraunhofer IKTS, we have decades of know-how in energy and environmental technology, photonics, sensor technology and test technology. We want to apply all of this to CEA infrastructures and to the needs of plants, which require heat, light, water and nutrients. The vertical cultivation cabinets are our test benches. This is where we combine our technology portfolio for this specific application. We take a holistic view of the interactions and balance between water use, nutrient production and energy. We link processes such as water cycles with heat management, aiming to achieve closed cycles. Today, controlled cultivation is technically still so complex that great leaps in efficiency are possible. Depending on the application scenario, systems of different scale and complexity are useful.

Which components and technologies do you develop and combine? How do you make them interact successfully?

We specifically test and develop whether our calculations also work in practice over the long term. We want to get to a point where we recover even the water the plant transpires. We use our membrane technology for media processing – e.g. water is treated through ceramic nanofilters and AOP, advanced oxidation processes. At the same time, sensors determine which nutrients the water still contains and which ones must be resupplied, in our case as a hydroponic solution. With the optimizations we have planned, a yield of 80 to 100 g lettuce per liter of water is realistic. That is twice as much as in previous vertical farms. Depending on the geographical latitude, lettuce cultivated on an open field is expected to yield 5 to 20 g per liter.

We rely on intelligent materials, such as flowable molded bodies made of innovative zeolite ceramics. The zeolites provide both latent heat and water storage: When the zeolites absorb

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heat, they release stored water through evaporation. When they absorb moisture at a later point, they release heat. If the airflow in the test beds is tightly controlled, the zeolites could be used to store excess heat during the day and release it at night when needed. This could replace energy- and maintenance-intensive, external compression chillers or fossil heating systems.

> “One of the strengths of the institute is to be able to solve technical challenges directly through functionalities in the material.”

We are going one step further and would like to integrate the entire controllable lighting technology into an energy management system integrated with the heat and humidity complex. Because where there is light, there is heat as well. By controlling plant exposure with pulse width modulation and synchronizing photon uptake and electron delivery, the energy requirement for light exposure could be reduced by 30 to 50 %.

Various inhouse biochemical and physical sensors could be used to determine whether the plants are doing well and how productive they are. They monitor the nutrient content, environmental parameters and plant pathogens. Integrated optical methods, such as laser speckle photometry, can be used to assess root growth or maturity. We want to orchestrate these diverse IKTS technologies as a modular, scalable system, fully digitized, for automated and even autonomous operation. In the end, it should be possible to build CEA systems so small and compact that they can be installed virtually anywhere, even in direct proximity to consumers. Agricultural production could then take place in locations that were previously unavailable for this purpose.

But surely each scenario – future indoor farms in, say, metropolitan areas or industrial parks – requires a varied ”configuration” ?

The concept is well suited for linking with commercial, industrial or urban infrastructures. Our goal is to integrate these systems into the respective environment in the best possible way. That is why we are using the modular approach. That may sound like an immense use of technology but we validate this from application to application using cost-effectiveness analyses and life cycle assessments. For instance, we look at the material and media flows and/or location interfaces that occur in the environment: What are the lighting conditions? Can renewable energy sources be combined and what do we do when there is no wind and the sky is overcast? Can I collect waste heat from server farms or hand over my own surplus to a manufacturing plant in the vicinity? Can I even use their emitted CO_2 directly, and how should it be reconcentrated and purified if necessary?

What about the nutrients supplied, such as phosphor and nitrogen – where do they come from and what are the development needs at this point?

The question of how nutrients can be recovered from organic residual material streams has been in our sights at IKTS for some time. We rely on biomass, such as sewage sludge from municipal sewage treatment plants or digestate from biogas plants. Ceramic membranes are used to separate the nutrients. At this point I should mention the abonocare® growth core, where we also test, in our vertical farming test beds, how well recyclates from biomass are absorbed by the plants. This is because the raw recyclates are often not yet to their liking at this stage. Phosphor tends to form alliances with other substances. The roots have difficulty absorbing it. Therefore, these phosphates must be specifically conditioned. The same applies to nitrogen: In organic fertilizers, this nutrient must first be dissolved from complex compounds. In nature, this happens automatically in the soil, a microbiological process. For a nutrient solution system as implemented at our institute, specific niches must be created for this purpose. In this regard, ceramic growth bodies make for great substrates.

What steps have you planned next?

Our long-term goal is a “toolbox” that enables users to connect them to any kind of indoor farm. These can come in the form of vertical cultivation cabinets like the ones we use, or greenhouses in different sizes and shapes, each optimally designed for the possible interfaces discussed here or elsewhere. For controlled cultivation, we want to pave the way for economic and ecological decentralized self-sufficiency – for secure and healthy nutrition and as a pillar of the bioeconomy.