Reintegration of Contaminated Sites in Urban Transformation and Metabolism applying Microalgae Production

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Abstract This paper presents the concept of a digital supported urban-integrated concept for the reuse of contaminated sites via agricultural production of basic materials and foodstuffs based on microalgae. The integration of algae cultivation into urban metabolism is intended to allow the material and energetic closure of circles in small and large loops.

Keywords: Urban Agriculture, Algae, Contaminated Sites, Industry 4.0, Circular Economy

1. Introduction

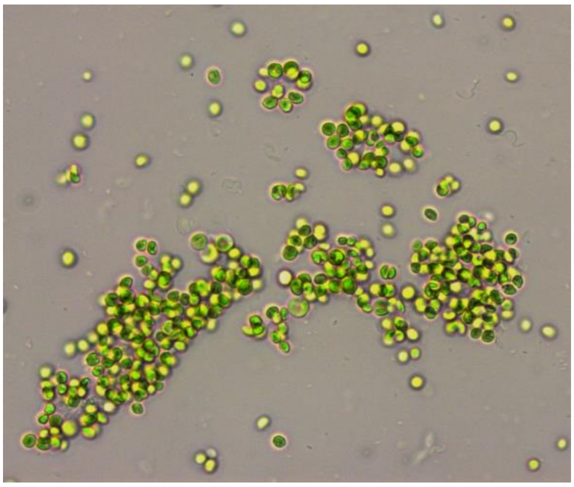
Against the background of an increasing world population one of the biggest challenges ahead is to limit the climate change and at the same time transform the resource supply in a sustainable way. At the same time the conventional agriculture, based on mineral and fossil raw materials and demanding huge area, is coming under increasing pressure. This is closely related to an

Urban growth is particularly linked to increased competition for resources in terms of e.g. area, energy and water. The greatest challenge of the urbanization process is to achieve an efficient use of resources adapted to current lifestyles and societal needs, while at the same time exhibiting a high resilience to changing climate and environmental conditions. Innovative agricultural systems have to be developed for this purpose.

2. The Potential in Micro-Algae Cultivation

The comprehensive use of microalgae as nutrition and the integration of their production into urban areas and urban metabolisms is one of the moon shot innovations that can revolutionize and improve current agricultural systems. The decisive advantage of micro-algae cultivation is their surface self-sufficiency, i.e. agricultural production irrespective of the soil quality and structure and the possibilities of co-use of land. In addition, microalgae have more versatile uses compared to conventional agricultural plants, a significantly higher growth and, consequently, a lower surface requirement. The following picture shows green algae *Chlorella vulgaris* cultivated in Hamburg

Figure 1: Green Algae *Chlorella vulgaris*



Through the use of specific cultivation systems, the production of microalgae can be integrated into the metabolism of urban areas centrally or de-centrally and synergies with energy supply and emission reduction systems as well as urban development functions can be established. For example, micro-algae cultivation allows the direct-coupled use of CO_2 from combustion processes, the direct local utilization of the nutrients phosphate and nitrogen from municipal, urban sewage as well as the co-use of supply and disposal infrastructures and logistics. In this way, a resource-efficient use adapted to regional and site-specific requirements can be ensured [Lam & Lee, 2012; Chen *et al*., 2011].

Currently, microalgae as well as microalgae components are primarily used in cosmetic products or as a food additive. Due to their cell composition, which contains essential ingredients for humans, microalgae have the potential to be the basic food of the future. The following list give the potential substances produced by or gained from micro algae.

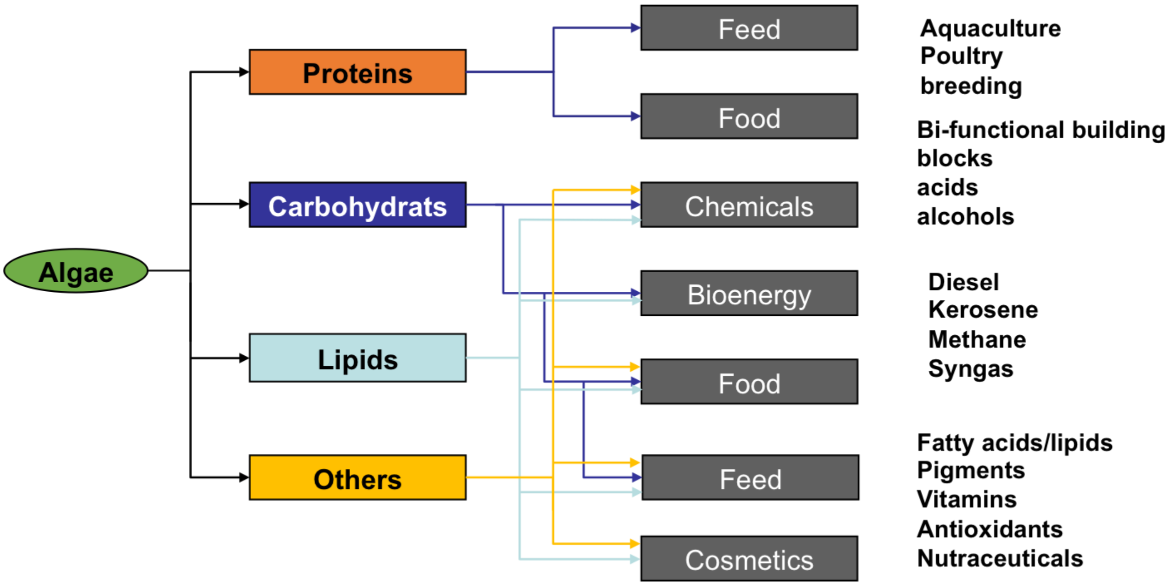


Figure 2 Algae potential for bio refinery concepts

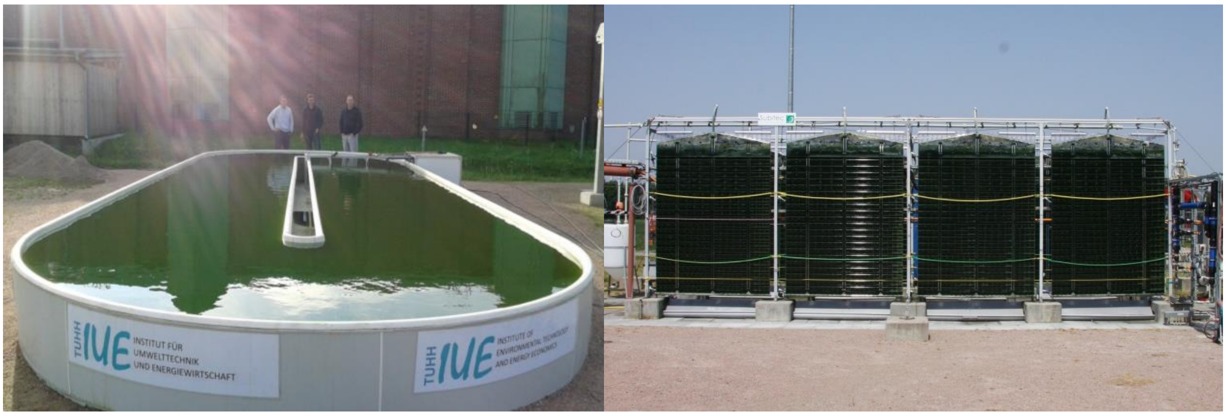


Figure 3: Algae cultivation at Hamburg Reitbrook in Flat Panel Air Lift Reactors (right) and Open Pond Systems (left)

It should be pointed out, however, that the cultivation of microsystems does not require either plant protection products or genetically modified organisms [Mussgnug *et al.*, 2010; Chisti, 2008].

At the same time, the integration of agricultural microalgae production in the urban reality requires an intensive participation process in order to evaluate current and future needs, to inform all relevant stakeholders about the

3. Urban Resource cycles

These newly developed urban resource cycles is covering the following functions:

Necessary preconditions for a sustainable implementation are high-precision real-time data, an exact knowledge of the interrelations and dependencies of the involved material cycles and a comprehensive, at the same time a predictable, use of all the technological possibilities and the resulting technological possibilities and design options.

The transformation of traditional trade worlds towards digital systems, which is accompanied by the digitization, has already shown that modern technologies generate decisive added value in society and the economy. A

opportunities and challenges, and congregate the synergies in the sense of the systemic goal [Vanthoor-Koopmans *et al.*, 2013; Wij els *et al.*, 2010].

Additionally, the techniques for the cultivation are still to be optimized as the preference differ between Open Ponds and Flat Panel Air Lift Reactors (see fig. 3).

holistic and integrated approach is required for the realization of innovative microalgae factories in urban areas.

Therefore, modern software infrastructures are the information technology base.

A) Supply of agricultural commodities - algae as basic foodstuffs

- Alternative basic supply with macronutrients such as carbohydrates, proteins and lipids

- Specific production of micronutrients such as amino acids, PUFAs or carotenoids

- Quality verification and validation of the products produced

B) Integration of agriculture - urban areas and urban

societies

- Co- and post-use of surfaces and area such as facades, roofs, landfill sites or wastewater

- Combining food supplies with urban life

- Participation of society in the design of agricultural economy systems

C) Agricultural production as part of urban metabolism - Sustainable closure of cycles

- Combine synergies such as CO_2 sequestration, nutrient and material flow recycling or thermal sinks and storages - Maximize resource efficiency

- Minimization of logistics costs for supply and disposal

- Transition to decentralized production and disposal

D) Digitization and IT-based self-regulating systems for agricultural schemes in urban areas

- systematic access to existing digitization experiences, such as Internet of Things, Industry 4.0, Big Data, digital ecosystems, augmented reality

- Development of simulation models for multiple networked material circuits as well as production and logistics processes

- multi-agency-based simulation and decision-making systems to capture and integrate the decentralized actors and decision-making processes involved.

The project enables the development of new technologies for the intelligent linking of processes coupled to natural material circles. The circular principle addresses the three dimensions of sustainability by saving resources, reducing costs, and at the same time enhancing social and urban life.

The project requires a close cooperation between different research disciplines and a comprehensive and timely communication and networking of local actors. Therefore, already developed and tested integrative interdisciplinary and trans-disciplinary research approaches will be applied and adapted to the concrete objectives and tasks of the project. The methods of life cycle assessment, the assessment of technology success as well as evaluation of social acceptance and social perspectives assess and secure the sustainability of the project.

The following figure shows the pilot location for the first integration of algae in urban strucktures on the old landfill Georgswerder in Hamburg.

4. Contribution to reach sustainability goals

An optimal management concept is created for every urban-integrated site for the production of microalgae, depending on current conditions. Within the production processes, decision alternatives are developed on the basis of short- and medium-term forecasts, which enable an optimal adaptation to changing context conditions. Furthermore, CO_2 is reduced by the microalgae cultivation in urban-integrated locations.

a) Scarcity of resources, land use

The orientation towards micro-locations, especially in the urban area, leads to highest efficiency as the resources are used where they are incurred. The area utilization is ideal as all areas are integrated and efficiently managed according to their potential. The agricultural sector is currently in a position to produce sufficient food. The major problems are the global distribution of food, post-harvest losses and insufficient exploitation of the site's potential. The competition between food and biomass production for the industry can be mitigated by the optimal use of the urban-integrated production of microalgae.

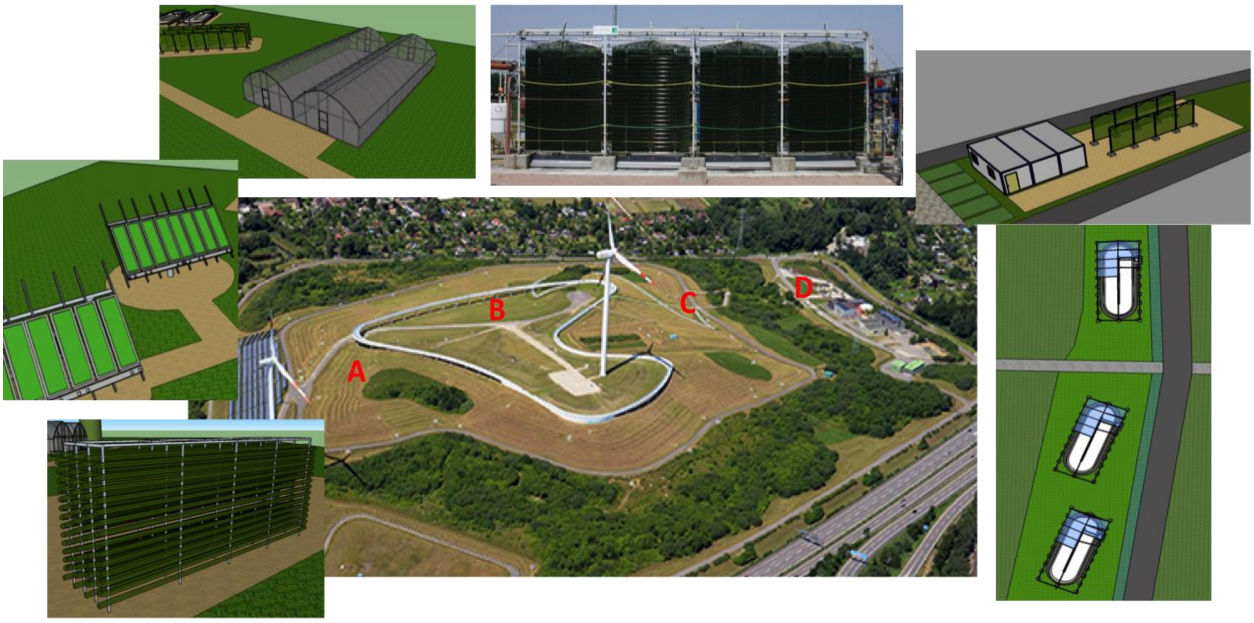


Figure 4: Implementation of Algae cultivation in urban structures, here on the old landfill Georgswerder in Hamburg

b) World population and urbanization

The methods and technologies are globally transferable as soon as there is a basic infrastructure that allows the use of the concepts. The production of micro-algae in urban integrated concepts enables the production of food with a high energy density per volume. In addition, the concepts of automation, management and decision-support systems create high-quality, attractive jobs.

c) Sustainable bio-based resource-efficient economy

Increasing the efficiency of micro-algae farming systems in urban-integrated concepts, i.e. increasing yields while reducing input through the optimal use and individual promotion of biological self-regulation mechanisms for each site, leads to sustainable use. Knowing the location potential, the microalgae cultivation linked to the medium-term weathering, leads to an optimal use of resources of nutrients, light and CO_2 on the micro-locations is possible. This results in an optimal urban area utilization while at the same time limiting the area consumption for food production.

5. Conclusion

The concept enables the development of new technologies for the intelligent linking of processes coupled to natural material circles. The circular principle addresses the three dimensions of sustainability by saving resources, reducing costs, and at the same time enhancing social and urban life.

The pilot implementation will be realized on an old industrial landfill in Hamburg, the landfill Georgswerder. The landfill is embedded in the city infrastructure and area reutilisation just started by using it for electricity production via wind turbines and photovoltaic systems. For the project the landfill location was chosen, because it offers area for cultivation, energy for supplying the local processes as well as the neighbouring residential areas and as a result of the new biomass production, heat produced inside the landfill to warm the cultivation in winter season and carbon dioxide for algae cultivation as an unused part of the landfill gas.

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