Storyline “Circular Bioeconomy” – extended abstract

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Background/Motivation

Currently, humankind consumes much more resources than Planet Earth is able to produce and absorb. The so-called global earth overshoot day illustrates this impressively. Since the 1970s, this virtual day of the year on which sustainable resource use comes to an end, has moved from end of December to early August. The situation is becoming even more critical as our life style is founded on a linear economy mainly based on the conversion of fossil resources into consumables which, after consumption, are finally leading to waste. This waste needs to be treated using resources and finally some shares can only be discarded thus adding to the resource and climate crisis. To secure life on Planet Earth we need - alongside more conscious consumption and behaviours - a transition towards a circular economy utilizing renewable feedstocks, which demands development of new technologies and societal adoption of their products. However, seen the extent of the use of fossil resources, any substantial substitute will exert an enormous pressure on the planet’s capacity to deliver renewables. Already today, there is a much-debated competition between the use of scarce agricultural land for the production of either food/feed or energy crops and raw materials for the chemical industry. Moreover, production of renewables by industrial agriculture is neither carbon neutral, as it consumes fuels and energy-rich fertilizers, nor environmentally friendly seen its detrimental effects on biodiversity and soil quality. This motivates our research towards a circular bioeconomy that also takes into account the scarcity of land.

Our mission

We strive to develop resource-efficient (bio-)technologies, which allow substituting current fossil energy and carbon resources, while minimizing their footprints on environmental quality, agricultural land and resources like water or minerals. We choose our research projects according to their expected environmental sustainability impacts, determined by their potential production capacities (e.g. biogas, hydrogen, commodities) and expected efficiencies, their avoided negative environmental, economic and socio-economic effects when compared against conventional production (e.g. based on petrol, palm oil), and their contribution to circularity (e.g. by the introduction of residual streams or secondary materials such as waste plastic waste).

Unique selling point – why this research at UFZ?

Our reaction schemes and processes are unique in that they rely (i) on solar energy, either directly via microbial photosynthesis or indirectly via (bio)electrochemical catalysis, the latter equally making use of renewable energy sources, (ii) on presently underexploited waste biomass (including lignocellulose/wood and plastics) and (iii) on CO_2 or synthesis gas. Most of our developments even skip the intermediate production of biomass and directly convert solar or electrical energy and CO_2 into products of value by using microorganisms as catalysts. Production is meant to take place in reactors thereby saving land, water, fertilizers and pesticides.

Technological contributions to a circular economy that are being developed at the UFZ (in RU4) are guided by first-hand knowledge and ongoing research on the availability of and competition for land

(RU1), energy and biomass (RU6) and water resources (RU2) as well as potential impacts on environmental quality and human health (RU3). The potential environmental impact of individual processes after implementation can be then assessed upfront and within a systemic context (RU5, RU6). As processes are typically based on microbial communities, they also build on a broad foundation of ecological understanding (RU1, RU4, iDiv).

Achievements

Biocatalysts developed or qualified for bioproduction comprise near-natural microbial consortia, specialized mixed cultures, and tailored production strains. As either organic wastes or sunlight and renewable electricity in combination with CO_2 are the principle feedstocks, emphasis is laid on microbial consortia[1] performing anaerobic digestion (AD), organisms derived from AD, photosynthetic bacteria, and electroactive bacteria. **Reaction schemes** comprise complete AD to biogas[2], biomethanation[3], syngas fermentation[4] and discontinued AD followed by chain elongation yielding platform chemicals[5]. A strong focus is on the transformation or *de novo* synthesis of chemicals using chemo-heterotrophic microorganisms[6] or cyanobacteria[7], cyanobacterial hydrogen production[8] and combinations of biological and electrochemical synthesis yielding commodities or energy carriers[9]. Pathway design is fostered by genetic strain engineering and accompanied by single cell biotechnology, and systems biology. **Reactor developments** serve to meet the specific demands of anaerobic consortia[10], photosynthetic bacteria[11], biofilm consortia[12] and electroactive bacteria[13]. They range from single cell reactors and microfluidic devices[14] used for strain characterization and optimization to pilot-scale reactors[15] that link process development to transfer and marketability. **Specific processes** beyond the above foci, but relying on unique extant expertise include for instance the conversion of kitchen oil and fat waste into high-prized isocitric acid[16], the recycling of plastic materials[17] and the recovery of phosphorous from wastewater streams[18]. Alongside technological developments, **assessments** of the impact of processes on resources, land use and environmental quality as well as their economic feasibility, suitability and importance for a future circular economy are performed[19].

Outlook - next steps

From now till the end of 2024: It is obvious that any shift from the use of fossil to renewable resources will result in partial decarbonisation and that any shift from primary production on arable land to production in reactors holds the potential to relieve land usage pressure with positive effects on e.g. pollution, resource use and biodiversity. However, the overall potential effects of above-mentioned bioprocesses after implementation are presently difficult to quantify due to their current early development stages. Research in this direction supervised by process developers of RU4, bio-economists of RU6 and modellers of RU5 is presently conceived and expected to deliver results before the end of 2024.

Prospects for PoF V: (i) Shifting primary production from arable land to reactors powered by solar energy, renewable electricity and waste biomass might be intensified for chemicals and extended to the feed and, prospectively, the food sectors. (ii) Our presently selective efforts to recycle, revalue or recover materials (polymers) and elements (C, P, metals) that are already in use might be put on a broader basis. (iii) The early stage assessment of technological developments, the environmental effects of their implementation and their fit in a developing circular economy might become a main emphasis and driver of process development.

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