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Bioenergy provision: utilizing contextual resources

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Bioenergy is an indispensable element of any future de-carbonized energy system. Bio-resources however are on the one hand highly contested and on the other hand context dependent sources. The first aspect calls for innovative and highly interlinked technology systems to realize the full potential of bio-resources. The latter aspect of bio-resources needs adapting technologies to their context, leading to tailor-made solutions that are defined by the availability of resources, their particular properties as well as requirements defined by their natural and the techno-economic context. Utilization of bio-resources therefore entails widening the focus of technology development, taking their spatial context as well as their role in eco-systems into account. The paper provides insight on the current state of discourse regarding the integration of bio-resource based technologies into their spatial, environmental and technological context.

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Introduction

The utilization of bio-resources for the provision of energy and material products poses new challenges for process engineers. These resources deviate from fossil and mineral raw materials in a number of important ways [1••]:

- They are contextual resources, that is, their availability varies with location and (in many cases) time;
- They have inferior logistical parameters compared to fossil and mineral resources;
- Although they are renewable and hence unlimited in their temporal availability, their extraction is strictly limited by the availability of other resources such as land, water and nutrients;
- As they are sole providers of food and feed, competition for these resources is fierce and growing.

These aspects of utilizing bio-resources requires a new and broadened approach to process design, including the whole value chain from field or forest to the provision of products and services [2].

Current utilization of bio-resources claims already a considerable part of the Net Primary Production (NPP), that is, the productivity of living organisms and eco-systems. Data provided in [3] estimate, that roughly a quarter of NPP is already under appropriated by human society, either by direct utilization or by the effects of land-use change. Given the limitation of NPP because of limited area and bio-productivity on our planet, expansion of human appropriation of NPP is both economically costly and environmentally risky.

Bio-resources are the basis of human nutrition but offer of a wide range of attractive ingredients for energy provision and industrial production as well. Together with their inherent limitation by NPP, this makes them particularly contested resources. A general trend therefore is that they are increasingly processed in highly efficient and complex bio-refinery systems [4••], which deliver a large number of products and services, energy provision being among them.

High efficiency in the use of these attractive and limited resources in complex technologies is however only possible, if these utilization systems take the properties of bio-resources fully into account. One major property is their dependence on their spatial, environmental and economical context as bio-resources availability and quality is defined by local climate, soil quality and cultivation. These contextual aspects therefore shape process design for bio-resource utilization technologies. This paper will focus on the current state of discourse regarding embedding bio-resource based energy and process technologies into their context. The paper will in particular look at integration of technologies into their spatial setting, their natural environment and into their respective local and regional technological system.

Spatial context integration of bio-resource based processes

Spatial context defines what bio-resources are available depending on climate and natural parameters like soil fertility and accessibility of water and essential nutrients [5]. The structure of land use moreover has strong implications on the logistics of the supply chain for bio-resources [6•]. A more intensive utilization of bio-resources and the reliance on renewable energy sources in general will therefore change the rules of spatial planning as this requires a re-orientation away from (fossil) point resources to area bound, de-central sources like biomass and solar irradiation [7]. Besides the change of the characteristics of sources, patterns of demand are also bound to change, as infrastructure becomes more energy efficient [8] and as transport may rely more on electricity and possibly methane or hydrogen than liquid fossil fuel. This gives raise to new planning principles for spatial development that have to take into account the systemic link between local/regional renewable sources and demand [9•].

Besides the change in demand structure and the re-orientation towards de-central resources, utilization of bio-resources requires a re-thinking of the importance and structure of transport within energy supply chains. Logistical properties of bio-resources differ considerably from those of fossil resources as they have usually lower energy and transport densities and higher moisture content (basic data can be found in [1••]). This deviation is even more pronounced for lower grade bio-resources like wood chips and straw or manure, resources that are not in competition to food and feed provision. In many cases available load volume of the transport vehicles will become limiting, increasing the number of journeys necessary to provide bio-resources to the processing sites.

Table 1 provides a brief overview on the energy required to transport bio-resources, compared to light fuel oil as a fossil competitor. The energy content of a particular resource in this table is a rough indicator for their content of valuable constituents. The numbers given in the table relate to the kJ of transport energy required to move 1 MJ of energy contained in a certain resource for 1 km. The last line gives the critical density of different transport vehicles. Below this density of a payload, volume becomes limiting and the ratio between payload and dead weight becomes increasingly disadvantageous.

The table clearly indicates the tremendous difference between fossil resources and bio-resources in general but also between different bio-resources. Compared to transporting oil by ocean ship, hauling manure with a tractor-trailer requires almost thousand times the transport energy per MJ moved. This increased importance of transport within the supply chains particularly of lower grade bio-resources requires a more de-centralised pattern of processing in smaller units as currently is the norm in the utilization of fossil resources [2,9•]. This in turn means that using these resources needs technologies that are adapted to and embedded into a local spatial context. High quality bio-resources (e.g. corn) or compacted bio-resources (e.g. wood pellets), although requiring considerably higher transport energy, may draw on a much larger area of resource supply. Such high quality bio-resources may be utilized in larger scale, centralized units. This means that logistical parameters and transport infrastructure become major factors influencing critical design parameters such as size of processing sites. They also have considerable impact on shape and structure of the supply chain, in particular if resources have to be purchased on a local/regional or on a continental/global market.

The spatial context has however considerable impact on the basic structure of bio-resource based technologies beyond defining their size. Land use pattern in a particular spatial context defines the range of bio-resources available for utilization. This opens possibilities for multi-feed bio-refinery systems. The structure of such multi-feed bio-refineries however have to be tailor-made to conform to the bio-resources available within their particular spatial context. Examples for such structures are reported in detail in [4••,8].

Integrating bio-resource utilization into the natural environment context

A major driver for renewable energy systems in general and bio-energy in particular is the assumption that these technologies exert considerably lower pressures on the environment than conventional fossil based technologies [10]. This is mainly based on the fact that growing plants, the source for all bio-resources, closes the carbon cycle directly: as much carbon is fixed by photosynthesis as is

Table 1

Transport energy for various bio-resources using different transport systems (own calculations, based on data in [1••])

	Energy density (MJ/m^3)	Energy for transport (kJ/MJ km)					
		Tractor	Lorry	Rail (electr.)	Rail (diesel)	Ship (river, av.)	Ship (ocean)
Manure	700	1.89	1.9				
Straw loose	970	0.425	0.19	0.034	0.118	0.072	0.017
Straw bales	1.990	0.232	0.13	0.021	0.073	0.039	0.013
Wood chips	3.100	0.149	0.1	0.015	0.052	0.025	0.01
Wood logs	7.000	0.097	0.09	0.012	0.042	0.015	0.009
Corn	10.000	0.079	0.09	0.012	0.042	0.012	0.009
Wood pellets	10.800	0.075	0.08	0.011	0.039	0.012	0.008
Light fuel oil	**35.800**	**0.031**	**0.03**	**0.004**	**0.02**	**0.004**	**0.003**
Critical density of vehicle (kg/m^3)		720	300	390	390	920	615