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# A decision support environment for the high-throughput model-based screening and integration of biomass processing paths

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ABSTRACT

The integration of renewable biomass feedstocks is receiving primal attention in energy and process industries. The conversion of biomass is typically faced with multiple options with respect to feedstocks, processing paths and product portfolios. The options for sustainable bio-based material have been highlighted in Association for the Advances of Industrial Crops Network (AAIC), that promotes the processing of crops towards industrial products. The systematic screening of these options is a major challenge. The paper presents a decision support environment that is capable of rapidly evaluating, screening and integrating biomass processing paths to bio-energy and other renewable products. The environment has built and makes use of an information repository that integrates data from various sources. A modelling environment enables the formulation and techno-economic and environmental assessments of both individual and integrated paths. The analysis involves optimization models for the high-throughput evaluation of options reporting recommendations and integrated paths when appropriate, as well as co-products more prominent to select. The proposed approach has been implemented into a software prototype and tested by industrial users, with the possibility to be extended and used by the wider community in the future. The prototyped modelling environment is outlined and illustrated by several case studies.



## 1. Introduction

The use of renewable biomass feedstocks is receiving primal attention in energy and process industries due to their potential in producing sustainable energy, chemicals and materials. In the renewable energy sector, biofuels and bioenergy already play an important role, and the steady growth in the production of biofuels (Demirbas, 2007; Huber et al., 2006) has developed into the concept of biorefining (Fernando et al., 2006; Clark, 2007). Exploring possible chemical products from biomass processing, NREL and PNNL (Werpy et al., 2004) produced an impressive list of potential building blocks, secondary chemicals, intermediates and final products. Corma et al. (2007) particularly reviewed bio-based products derived from heterogeneous catalysis. Hermann and Patel (2007) and Haveren et al. (2008) discussed the replacement of mineral feedstocks by renewable biomass components. The actual potential of biomass-based industry is huge. In Europe alone, it is predicted that about 950 biorefineries could be developed by 2020 with the potential to generate a yearly revenue of 32 billion EURs (Bloomberg, 2010).

The options available for sustainable sources of biobased material have been highlighted in AAIC Network (www.aaic.org). The diversity, the volume and the dispersion of the data collected by the AAIC Network explains the need for a systematic optimization approach. A high-throughput evaluation of the available options is a coveted function. Options are compounded by several feedstocks, various possible intermediates, a large range of products and numerous processing technologies (Haveren et al., 2008). A systematic approach is required to select and integrate processing options to best suit available resources and markets. To meet the challenge, a decision support system should combine models and data from a variety of sources enabling high-throughput functions and assisting decision makers to review profitable paths. Such paths are increasingly complicated in the cases where these paths are integrated, complementing each other with respect to production, efficiency and environmental integrity.

A high-throughput decision support environment can be assisted dramatically by systems engineering technology. Systems approaches offer powerful methods to optimize designs and systematize improvements of biomass processing systems, biorefineries in particular (Kokossis and Yang, 2010; Dimian, 2007; Klatt

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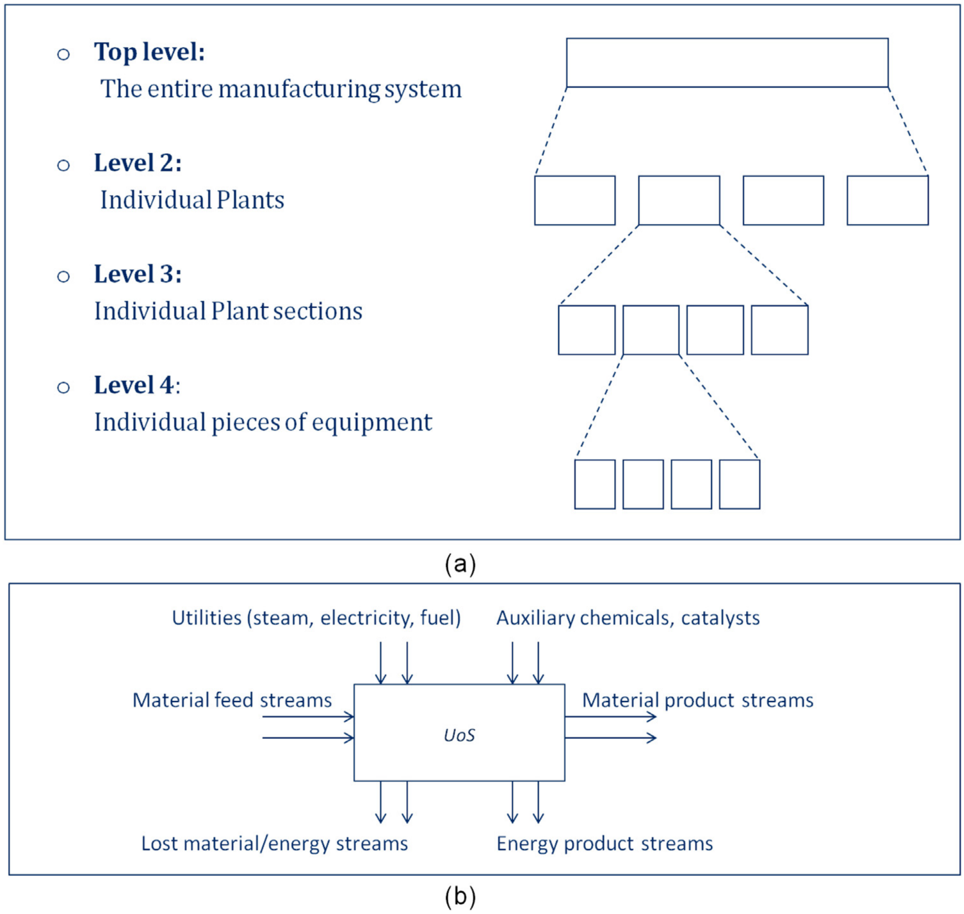


**Fig. 1.** Modelling biomass processing paths. (a) Different levels of modelling analysis; (b) representation of a UoS.

and Marquardt, 2008). Existing work has been carried out in several areas, including modelling and simulation (Haas et al., 2006; Cardona and Sanchez, 2006; Piccolo and Bezzo, 2008; Gutierrez et al., 2009), techno-economic assessment (Patel et al., 2012), process integration and optimization (Sánchez et al., 2006; Gassnet and Marechal, 2012) and supply chain design and analysis (Kaylen et al., 2000; Sammons et al., 2007; Sadhukhan et al., 2008; Akgul et al., 2012). Although systems tools have found applications in these areas, most of the existing work has focused on individual processes or plants (or their parts) of known types. Cucek et al. (2011) extend the scope and explore various routes and options for specific products (e.g. bioethanol) and co-products. Further to the use of optimization, a systematic screening of the large number of options requires a framework to combine available modelling and information about the problem components. The use of the framework bears particular importance to strategic stages of development when product portfolios remain unknown and the potential to valorise biomass is largely unclear.

This paper presents a decision support approach that is already translated into a prototype software environment. The environment enables the systematic screening and the selection of biomass processing schemes in terms of feedstock, intermediate and final products and processing technologies. The approach combines simulation, synthesis and optimization functions in the selection of biomass-based production paths.

## 2. Methodology

The high-throughput environment proposed for decision support (DSE) features three principal aspects. A structured approach is applied to relate outputs (decisions) with inputs (feedstocks, models, technology and economic data). A systematic procedure is employed to evaluate biomass routes to products through different processing technologies. Additionally, it scopes for integrated scenarios using optimization and synthesis technology. These aspects are addressed in Sections 2.1, 2.2 and 2.3, respectively.

### 2.1. Building the repository of modelling information

Modelling information includes material flows, conversion technologies, logistics etc. In the context of this work, modelling information is collated around individual biomass conversion processes with different levels of modelling (model granularities) being differentiated. It also requires a definition of what constitutes an elementary modelling unit. This section will discuss these conceptual issues and subsequently present a repository of modelling information established according to the proposition. Similar principles can be applied to integrate biomass conversion with logistics.

#### 2.1.1. Modelling levels and elementary modelling units

As shown in Fig. 1a, there exist several levels to locate a particular component (Levels 1–4) of a manufacturing system. Level 1 constitutes of entire manufacture system where boundaries are considered from feed handling to factory gate i.e. before it is transported to the user or consumer. This level requires crude and heuristic approaches. Level 2 contains individual plants, each producing one or several major final products or intermediate products, e.g. pyrolysis plant, gasification plant, bioethanol plant, etc. In the context of biomass conversion, they are referred as processing steps. Level 3 relates to individual plant sections, each consisting