Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

From petrochemical complexes to biorefineries? The past and prospective co-evolution of liquid fuels and chemicals production in the UK

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ABSTRACT

A debate has begun on the potential for renewable raw materials (RRM) to substitute fossil hydrocarbons in synthetic products. A related debate has arisen in the liquid fuels sector with contested proposals for the expansion of biofuels production. A transition to *integrated biorefineries* as analogues of oil refineries has been advocated, to enable RRM to compete with petroleum and minimise environmental impacts. Transitions between technological systems involve evolutionary processes, in which change emerges from reinforcing feedbacks between different levels of the socio-technical system. The past both shapes the current system and influences and constrains future options and pathways. Thus, over the past half century oil refiners and the associated petrochemical industry have achieved a high level of integration that challenges the competitive development of RRM, for which the full range of necessary technologies and product families are not well established and the commercial and technical risks are high. This paper explores a case study of the transition from coal-based to petrochemical feedstocks in the UK (1921–1967), applying a system dynamics approach to extract and elucidate the key interrelationships between technologies, policy and society. The findings and insights are then used to inform a discussion of scenarios for future biorefinery technologies, with a focus on bio-based chemicals.

Keywords: Biorefinery; Multi-level perspective; Transition pathways; Renewable raw materials; Green chemistry; System dynamics

1. Introduction

Biorefinery ideas and initiatives are discussed increasingly in several literatures about cleaner energy, greener chemistry, process engineering, forestry, management and others. Most ideas arrive fully formed, portraying a novel design or technique for a biomass processing facility that has yet to be built and proved. While most such facilities have yet to receive financial support or even proof of concept, numerous less complex plants are being constructed to transform biomass feedstocks into saleable fuels, chemicals, fibres or feed; this makes the *integrated biorefinery* appear a more long-term ambition. Relatively little attention has yet been paid, moreover, to the industrial dynamics of biorefinery development, and how existing interdependencies between firms, infrastructure and research objectives might shape or constrain biorefinery design. This paper discusses transition pathways to industrial use of renewable raw materials, building on insights from innovation theory and an exploration of the history of petrochemicals production.

The European chemical and fuels industries are being pressed to consider alternative raw materials for the future, for at least two reasons. Concerns about high current feedstock costs and potential oil supply constraints have instigated a debate about the sustainability of petroleum-based products. Environmental concerns and an eastward migration of bulk chemical production have likewise raised the attractiveness of renewable raw materials (RRM) based on biomass. The sustainability of some biofuels has been challenged in several recent scientific and political publications,

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Received 9 October 2008; Received in revised form 2 February 2009; Accepted 20 February 2009
0263-8762/$ – see front matter
doi:10.1016/j.cherd.2009.02.008

presenting questions about whether and how to support their future development (EAC, 2008a,b; Fargione et al., 2008; Mitchell, 2008; RFA, 2008; Searchinger et al., 2008). It is increasingly being suggested, moreover, that the greatest environmental, economic and social benefits might be achieved by the use of *non-food* biomass resources, exploitation of the whole feedstock and, where possible, production of high value co-products.

The *integrated biorefinery* concept encapsulates this approach. Thus, Ragauskas et al. (2006) propose 'a total integration of innovative plant resources, synthesis of biomaterials, and generation of biofuels and biopower', leading to biorefineries that will parallel modern oil refineries. Koutinas et al. (2007a) consider such biorefineries to entail the 'economic conversion, fractionation, or extraction of a spectrum of biomass sources through integrated physical, biological and chemical processing for the production of various commodities and specialities'. This corresponds closely to a working definition of the biorefinery used by the IEA Task 42 Working Group and the EU Biopol project (Biopol, 2007).

Nevertheless, such broad definitions and analogies with petrochemical refineries provide limited guidance as to likely future plant designs and profitable technology/product combinations.

Thus, Sammons et al. (2008) and Chamboost and Stuart (2007) have recognised a problem of complexity, related to optimal product allocation, given that the full range of necessary technologies and product families is not well established. And, although Meiser et al. (2008) present a commercial strategy for managing some of the associated risks to enable RRM to compete with petroleum and minimise environmental impacts, in our view, the literature has paid insufficient attention to how current research, design and policy activities might influence the longer term application of biorefinery technologies. We also believe that lessons and insights can be drawn from the analysis of previous technological transitions.

Consequently, this paper aims to explore the potential for and the constraints on a transition to a new technological basis for chemical and fuels production built on bioresources. In doing so, it draws on the growing volume of recent research on technological transitions, which has been increasingly applied to policy formulation for sustainability. It applies this analytical approach to the exploration of previous transitions, in search of insights into the factors and interactions that might advance or retard the prospective co-evolution of fuels and chemicals production in the UK and the development of biorefineries.

The paper has the following structure. Section 2 outlines the socio-technical theories relevant to the introduction of renewable raw materials (RRM), while Section 3 sets out the empirical approach taken in this paper to applying them to an earlier relevant transition, the introduction of petrochemicals in the UK up to 1967. Section 4 presents key results of this research. Section 5 then uses the insights gained from this qualitative study to inform a discussion of possible futures for RRM in the UK. Section 6 concludes the paper.

2. Theoretical background from the innovation literature

Transitions between technological systems have been characterised as evolutionary processes, in which change emerges from the selection of new technologies that fit with socio-economic criteria relating to performance, cost, familiarity and changing user preferences. This is an approach that embraces concepts from several parts of the literature on innovation, including *bounded rationality*, *diversity*, *selection*, *path dependency* and *lock-in*, and co-evolution (Van Den Bergh et al., 2006). Thus, reinforcing feedbacks between different 'levels' of the socio-economic system are seen as enabling novel technologies, or combinations of technologies, to diffuse into the economy and ultimately to displace existing technologies and practices, or to themselves be overtaken and disregarded. One

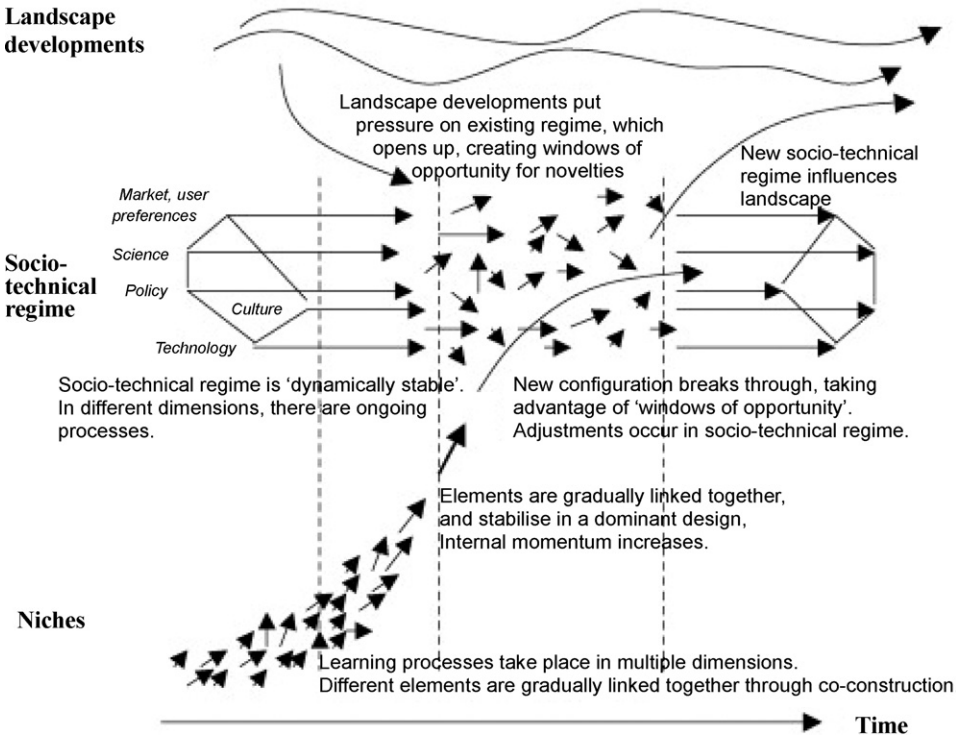

Fig. 1 – Multi-level framework for the analysis of socio-technical transitions. Adapted from Geels (2002).