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Punctuated continuity: The technological trajectory of advanced biomass gasifiers

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HIGHLIGHTS

- Advanced biomass gasification, as important enabling technology for biofuels and the bio-based economy, has been lacking success despite decades of research and development.
- We try to explain this by reconstructing its technological trajectory.
- We focus on processes of variation and selection, and interaction between local demonstration projects and the upcoming technological field.
- The development of the technology over each period shows strong variation.
- Long RD&D times in combination with major changes in the socio-economic context have resulted in discontinuities that even affected premium technologies.

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ABSTRACT

Recent interest in biofuels and bio-refineries has been building upon the technology of biomass gasification. This technology developed since the 1980s in three periods, but failed to break through. We try to explain this by studying the technological development from a quasi-evolutionary perspective, drawing upon the concepts of technological paradigms and technological trajectories. We show that the socio-economic context was most important, as it both offered windows of opportunity as well as provided direction to developments. Changes in this context resulted in paradigm shifts, characterized by a change in considered end-products and technologies, as well as a change in companies involved. Other influences on the technological trajectory were firm specific differences, like the focus on a specific feedstock, scale and more recently biofuels to be produced. These were strengthened by the national focus of supporting policies, as well as specific attention for multiple technologies in policies of the USA and European Commission. Over each period we see strong variation that likely benefitted the long term development of the technology. Despite policy efforts that included variation and institutionalization, our case shows that the large changes in socio-economic context and the technological challenges were hard to overcome.

1. Introduction

Over the past few years, energy from biomass has received ample interest, with special attention for biofuels, bio-refineries and the concept of a bio-based economy. Crucial to these developments is the technology of biomass gasification. Biomass gasification is the thermochemical breakdown of biomass – at high temperature and frequently also at high pressure. Input can be a diversity of biomass feedstock, although each requires a somewhat specialized technology. In the gasifier, the feedstock is converted to syngas (also called producer gas) that mainly consists of carbon monoxide and hydrogen. Clean syngas can subsequently be converted in several products: heat, power, chemicals and fuels – like methanol and Fischer-Tropsch diesel.

Biomass gasifiers come in a variety of designs. Typically applied at smaller scale are the updraft and downdraft gasifiers. Simple updraft gasifiers produce syngas full of contaminants and are mainly applied in heat applications. Downdraft gasifiers produce cleaner syngas that is mainly applied for power production by engines. At larger scales there is a diversity of fluidized bed and entrained flow designs that, combined with extensive gas cleaning, can produce clean syngas for the production of biofuels, chemicals and power. We focus on the latter category of advanced gasifiers.

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Advanced gasification fitted social concerns well over the past decades. As such, it received a lot of interest and support (Kirkels and Verbong, 2011), but only became applied in a few research, development and demonstration (RD&D) niches. This raises questions from an innovation perspective. What is limiting the success of this technology? And what does this mean for its future application? Only recently, the long-term development of biomass gasifiers has been studied. Hellsmark, (2010) takes a Technological Innovation Systems (TIS) perspective on European countries that dominated developments in biomass gasification - Sweden, Finland, Germany and Austria. Kirkels and Verbong, (2011) provide an overview of global long term developments in biomass gasification based on multiple indicators and literature, showing that interest came in three distinct waves: in the early 1980s with a focus on methanol production; in the 1990s with a focus on power production by Integrated Gasification Combined Cycles (IGCC); and after 2000 with a focus on biofuels.

In this paper we will follow a complementary approach. We will reconstruct the technological development of advanced gasifiers and try to answer the following questions: 1) what has influenced the initial momentum and focus of the technological path; and 2) what impact did the developments in the technological path have on the success and failure of the technology. For the latter, we will address four sub-questions: a) what have been the dominant technologies and companies; b) what have been dominant research themes and lessons learned; c) to what extent did this result in patterns of variation, selection and (dis)continuous technological paths over time; and finally d) how did this influence the promise and failure of the technology? We will conduct extensive literature study and construct an overview of demo plants in order to answer these questions for each of the three periods identified by Kirkels and Verbong. In the next paragraphs we will introduce the concepts that we will be building upon, followed by the methodology. Next we will describe for each period the empirical results. And finally we will come to conclusions and discussion.

2. Conceptual framework

We use an *evolutionary perspective* on technological change, starting from the work by Dosi, (1982) and Nelson and Winter, (1982). It is evolutionary in the sense that it includes processes of variation, selection and retention. Variation comes from early engineering efforts in RD&D, in a phase characterized by high uncertainties, little alignment and no lock-in. Sources of variation are firm-specific differences and bounded rationality. Selection mainly takes place upon market introduction: picking technologies that perform best in a given socio-economical context. And finally retention, or continued existence, is driven by processes of success and institutionalization, e.g. setting standards, sharing knowledge, etc.

As our interest is in both continuous technological change as well as discontinuities, we will be drawing upon the notions of technological paradigms and technological trajectories by Dosi, (1982). Dosi starts from a broad notion of *technology* as:

a set of pieces of knowledge, both directly ‘practical’ (related to concrete problems and devices) and ‘theoretical’ (but practically applicable although not necessarily already applied), know-how, methods, procedures, experience of success and failures and also, of course, physical devices and equipment.[1]

Based on this, he defined *technological paradigms* (or research programs) in analogy of Kuhn's notion of scientific paradigms as:

an ‘outlook’, a set of procedures, a definition of the ‘relevant’ problems and of the specific knowledge related to their solution.[2]

According to Dosi, the technological paradigm embodies strong prescriptions on the directions of technological change to pursue, and those to neglect. The identification of a technological paradigm relates to the generic tasks to which it is applied, the material technology it selects, the physical or chemical properties it exploits and the technological and economic dimensions and trade-offs it focusses upon. These define an idea of progress as the improvement of the trade-offs related to those dimensions. As such Dosi sees *continuity* in technological development, or development that adds up to a *technological trajectory*, as a pattern of normal problem solving within the technological paradigm to achieve progress; while *discontinuities* are associated with the emergence of a new paradigm. Some of the characteristics of a technological trajectory are: it consists of a series of small innovations (local incremental variations) that built upon each other and as such are cumulative; once a path has been selected and established, it shows a momentum of its own and as such it might be difficult to switch from one trajectory to an alternative one; there are complementarities among trajectories; and it is doubtful whether it is possible a priori to compare and assess the superiority of one technological path over another.

Geels, (2002) and Rip and Kemp, (1998) have argued against such a narrow perspective on technological change, as this put too much emphasis on the embedding of routines in the minds of engineers. The outcome of the innovation process is also determined by other social groups like policy makers, users and scientists. More recent innovation theories, like the field of Transition Studies that includes theories of Strategic Niche Management and the Technological Innovation Systems, take this criticism into account and approach technological change as a *quasi-evolutionary* process (Faber et al., 2005; Raven, 2006). The process is called quasi-evolutionary, as the variation of technologies is not random. Researchers and RD&D departments do take into account both what they consider most promising technologies based on performance in lab or merely by expectations, as also the perceived future socio-economic context in which the technology will have to perform. These approaches put more emphasis on cognitive rules like goals, problem agendas and expectations. According to Geels and Raven, (2006) expectations, visions and beliefs have the dynamic of self-fulfilling prophecies, because they guide research and development activities that work towards realizing them. While shared cognitive rules and expectations create stable trajectories of technological change, change in the direction of the technological trajectories depends on a change in the content of cognitive rules and expectations.

Geels and Raven argue (2006) that it is at the level of *communities or emerging fields* that the emerging technological trajectory can be found – see Fig. 1. This level is building upon (series of) local projects, characterized by actors directly involved in those projects and local variability (local networks, project definitions, skills). The global network consists of actors who have some distance to the project. It refers to an emerging field or community. It is characterized by abstract, generic knowledge shared within the community (theories, technical models, agendas, expectations, etc.). The translation of local outcomes into generic lessons and cognitive rules requires aggregation activities (e.g. standardization, model building) and the circulation of knowledge and people to enable comparison between local practices and formulation of generic lessons (e.g. by conferences, workshops, proceedings, journals, etc.). According to Geels and Raven, the interplay between local projects and the global

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[1] Dosi, 1982, p151/152.

[2] Dosi, 1982, p148.