Lignocellulosic Ethanol: The Path to Market

Raphael Slade (*) and Ausilio Bauen
Imperial College Centre for Energy Policy, 3rd floor Mechanical Engineering, Exhibition Road, London SW7 2AZ,UK.(*) corresponding author; email: r.slade@imperial.ac.uk

ABSTRACT: Market deployment of lignocellulosic ethanol requires practical and plausible development paths that are able to support progress from existing small-scale demonstration plant to large industrial installations. Moreover, these development paths must be sufficiently attractive to persuade developers and investors that this technology remains an opportunity worth pursuing. This paper explores the opinions and practices of companies (and other market actors) who are pursuing lignocellulosic ethanol technology in the context of the academic literature on innovation. The premise that underpins the analysis is that the decisions that these actors make, and their appraisal of the potential offered, will, at least in the short term, determine the path to market. We conclude that corporate interest in lignocellulosic ethanol is principally driven by the desire to expand upon existing business assets or acumen. Market dominance is expected to come from privileged access to feedstocks and vertical integration. Large scale LE plants are largely regarded as hypothetical. The most credible paths to market (at least in the short term) are considered to be intermediate scale facilities, closely integrated with other industrial processes such as CHP, district heating, or conventional ethanol production.
Keywords: ethanol, lignocellulose, biofuel, market, demonstration, project development.

1 INTRODUCTION AND BACKGROUND

The cost effective production of transport fuels from biomass is essential if the EU aspiration to substitute 10% of transport fuels with sustainable alternatives by 2020 is to be met [2]. The hope, voiced by the Parliament's Industry and Energy Committee, is that at least 40% of the 2020 target will come from second-generation biofuels, and therein lies a challenge: second-generation conversion technologies are not yet commercial. Multiple pathways are being investigated around the globe, but dominant pathways have yet to emerge and business models have yet to be proven. Nevertheless, expectations are running high and there has been significant investment in R&D in the US, Europe and Asia.

The production of ethanol from lignocellulosic biomass is commercially and environmentally one of the most promising second-generation options, and in 2007 the US Department of Energy (DOE) provided more than US$1 billion toward lignocellulosic ethanol (LE) projects. Their goal was to make the fuel cost competitive at $1.33 per gallon, when deployed at scale, by 2012. The majority of studies also suggest that LE will result in superior greenhouse gas savings compared to ethanol produced from starch.

Despite favourable predictions for cost and environmental performance, market deployment requires practical and plausible development paths that are able to support progress from existing small-scale demonstration plant to large industrial installations. Moreover, these development paths must be sufficiently attractive to persuade developers and investors that LE remains an opportunity worth pursuing. For a pre-commercial technology such as lignocellulosic ethanol the path to market is inherently speculative [1]. Yet, many of the market agents who might be expected to play a role along the development path are already in place, including technology developers, feedstock suppliers, potential investors, government agencies etc. The premise that underpins this analysis is that the decisions that these agents make, and their appraisal of the potential offered by LE, will, at least in the short term, determine the path to market.

This paper is presented in 2 parts. The first part reviews the key concepts to be found in the academic literature on innovation. The second part explores the opinions and practices of existing market actors and thereby builds a picture of the options available, the decisions taken, and the underlying reasons for these decisions.

2 PART 1: INNOVATION THEORY

Developing, demonstrating and commercialising LE production demands both specific technical improvements and systemic technological change. Yet, the actions that companies and policy makers need to take in order to make these improvements and stimulate change are not necessarily unique. Comparable measures may be required to advance other early stage technologies, both in the area of renewable energy and more broadly in fields as diverse as pharmaceuticals and consumer electronics. Innovation theory is, in essence, the body of knowledge gleaned from previous attempts to commercialise technology and stimulate change.

There is a large body of literature on innovation, which can be divided into three main strands: (i) *innovation as a strategic management issue*; (ii) *models of technological diffusion*; and, (iii) *innovation as a systemic process*. Yet, innovation is something of a catch all term. It is usually differentiated from invention (defined as the first discovery of new product or processes [3]) but may be used interchangeably with technological change to describe the steps required to get the new product to market. Innovation may be classified as incremental, radical, or disruptive [4] [5] depending upon whether it originates within, or outside, the mainstream. It may also refer to a new product itself, to a stage in a product's lifecycle [1], or to an iterative process of invention, and application that links technical, societal and political change [6]. A concise introduction to innovation is provided by Foxon [7]. For our purpose, no specific definition of innovation is required. It can be taken in one of the original senses: innovation is simply "getting a new thing done" [3].

Commercialisation, arguably the endpoint of the innovation process, is similarly nebulous. There is no single definition of *commercial*, nor is it clear whether *being commercial* necessitates the absence of subsidies. The dictionary definition is simply *'able to yield or make a profit'*. A more comprehensive definition used by the United Nations Environment Programme is as follows:

> *'Commercialisation means that the manufacture and sale [of a renewable energy technology] is a profit driven process in that the income derived (which may or may not include subsidies) is sufficient to make it a worthwhile activity for the entrepreneur'* [8]

Whether an activity is '*worthwhile [...] for the entrepreneur'* depends upon the judgements made by investors: the size of the investment, the opportunity cost, its perceived risk etc. The inclusion of both subsidised and unsubsidised markets in the definition also acknowledges that it may be socially or politically desirable to support particular activities, for example, those that reduce GHG emissions or internalise other externalities.

2.1 Innovation in the strategic management literature

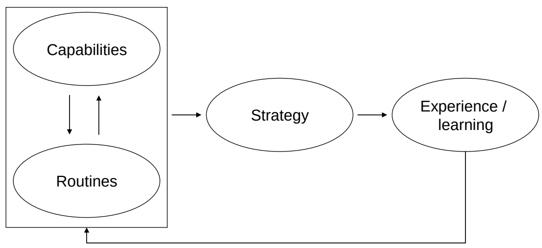
The strategic management literature focuses on companies decision making processes and seeks to build a bottom-up picture of a firm's individual behaviour of in the face of technological change. It is underpinned by four fundamental concepts: *bounded rationality*, *organisational routines*, *capabilities* and *strategy*.

Bounded rationality holds that companies are rational economic actors constrained by limitations of information availability, computational capacity, and time [9]. In the face of the uncertainty and imperfect foresight that this entails, companies rely upon organisational routines to simplify and make decisions [10]. Examples of organisational routines (which are simply dominant forms of behaviour) include training managers to reject any project that does not deliver a minimum financial return, or to reject new ventures that are small in relation to the size of the original company [11]. Organisational routines are also determined by a firm's history and capabilities. History is important because routines that have benefited the company previously are likely to be refined with the benefit of experience (learning by doing) [12] and so may become entrenched. Capabilities are the unique combinations of resources and competencies that distinguish a firm from its competitors [13], and includes tacit knowledge in addition to tangible and intangible assets. At least in the short run, capabilities tend to be difficult to replicate and can form the basis of a firm's competitive advantage.

Like innovation, strategy is another broad concept. A traditional definition holds that strategy is deliberate: the "determination of basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals" [14]. Subsequent researchers, however, have recognised that strategy can emerge out of unintended and undirected actions that have coalesced over time to become the dominant pathway for a firm [12]. A distinction can therefore be made between deliberate and emergent strategies [15]. An alternative and more functional view of strategy is that, whether deliberate or emergent, its purpose is to position a firm in the market in order to make it defensible against competition. Five determinants of competition, or forces, are widely recognised. These are the bargaining power of customers and suppliers, the threat of new entrants and substitute products, and the level of competition in the industry [16]. To position itself against these forces, a firm may seek to build new capabilities (to innovate), or find niches in the market in which to exploit its existing capabilities. Examples of strategic choices include: becoming a cost leader, seeking to differentiate products in the eyes of customers, moving out of a highly competitive markets, etc. If a defensible position within the existing market cannot be found, another option remains: lobbying government to change the rules so that competition is reduced or so that existing capabilities can be exploited more profitably. Corporate political activity, undertaken to effect such change, may include lobbying, advocacy, financial contributions to political parties, constituency building, etc.

The interaction between strategy, organisational routines and capabilities is essentially dynamic. As a company pursues its strategy in the marketplace it will gain experience that will enable it to extend its capabilities and modify its routines. This relationship is summarised in Figure 1.

The strategic management literature thus describes a framework for analysing a firm's decisions, and provides a rationale for firms to innovate: investments in R&D (and learning by working) make sense because new technologies can improve a firm's competitive position. Investments in new technology may also provide a hedge against uncertain and unforeseen risks [1]. The limitation of the strategic management approach is that the diffusion of a new technology involves numerous firms with different capabilities pursuing diverse strategies. Whilst the management literature helps identify the options available, for any individual firm, the decisions that result in the selection of technology, or the selection of a particular strategy, are often so numerous and complicated that they cannot be modelled individually (ibid). This limitation is to some extent addressed by technology diffusion models and systemic studies of innovation.

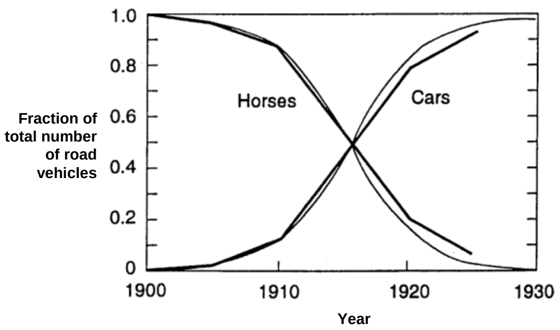


Adapted from [17]

Figure 1: An organisational learning framework for strategy making

2.2 Technological diffusion models and experience curves

Historically, technologies entering and exiting the market have displayed characteristic patterns of diffusion, substitution and senescence, which can be described using S-curves. The classic example is the substitution of horse drawn carriages by motor cars in the USA, shown in Figure 2. Because the basic patterns diffusion and substitution are largely invariant across a wide range of different examples [1], stylised models of technological evolution may be developed. These models characterise technological lifecycles into stages according to the technology cost, market share and learning rate. One such characterisation scheme is shown in Table 1.



Source: Nakicenovic in [1]

Figure 2: The substitution of horse drawn carriages by motor cars

Although the patterns of diffusion (substitution) appear invariant, neither the maximum extent of diffusion (or substitution) nor the time constant Δt – the time taken to grow from 10 to 90% market share – can be determined from historic data. Nor can diffusion models fully explain which technologies attract investment. Nonetheless, diffusion models are useful heuristics for technology modelling and historic observations can help guide the selection of an appropriate Δt: the greater the scale, infrastructure requirements and technical interdependence, and the lower the relative advantage over the incumbent technology, the longer Δt is likely to be.

Similar to technical diffusion models, the concept of experience (learning) curves originates from empirical observations of technological change, and specifically the observation that technology unit costs often decrease at a more or less fixed rate (the progress ratio (PR)) with every doubling of cumulative production. This idea was incorporated into mainstream economic literature by Arrow [18] in a review of 'the economic implications of learning by doing', but was first observed and documented in 1936 in relation to the efficiency of air frame production [19]. The concept has been widely applied to the manufacturing sector [20] and an overview of its application to energy technologies is given by McDonald and Schrattenholzer [21].

The experience curve principle is attractively simple but a number of methodological issues arise in its application. In particular: (i) production costs are difficult to determine, market prices are often used as a surrogate but this may introduce additional variables (e.g. the affect of advertising campaigns etc.); and, (ii) cumulative output is often used as a substitute for accumulated experience [22]. It is also important to bear in mind the underlying reasons why cost reductions may occur. Factors may include: (i) learning by doing, (ii) innovation and R&D, (iii) standardisation, (iv) economies of scale and redesign, (v) improved network interactions [23]. These methodological issues, and the importance of avoiding double counting when using learning curves in combination with other analytical approaches, suggest that long term projections of learning rates should be treated with caution.

Notable applications of experience curves to bio-energy technologies in the academic literature include the documentation of the Brazilian ethanol learning rate

Stage	Mechanisms	Cost	Commercial Market share	Learning Rate	
Invention	Seeking and stumbling upon new ideas; breakthroughs; basic research	High, but difficult to attribute to a particular idea or product	0%	Unable to express in conventional learning curve	↑ "Radical"
Innovation	Applied research, development and demonstration (RD&D) projects	High, increasingly focused on particular promising ideas and products	0%	Unable to express in conventional learning curve; high (perhaps > 50%) in learning curves modified to include RD&D (see text)	↓
Niche market commercialization	Identification of special niche applications; investments in field projects; "learning by doing"; close relationships between suppliers and users	High, but declining with standardization of production	0–5%	20–40%	↑ "Incremental"
Pervasive diffusion	Standardization and mass production; economies of scale; building of network effects.	Rapidly declining	Rapidly rising (5–50%)	10–30%	↓
Saturation	Exhaustion of improvement potentials and scale economies; arrival of more efficient competitors into market; redefinition of performance requirements	Low, sometimes declining	Maximum (up to 100%)	0% (sometimes positive due to severe competition)	↑ "Mature"
Senescence	Domination by superior competitors; inability to compete because of exhausted improvement potentials	Low, sometimes declining	Declining	0% (sometimes positive due to severe competition)	↓

Source : [1].

Table 1: Stylised stages of technological development and typical characteristics

during the PROALCOOL program [24]. This programme was established in 1975 and the progress ratio was found to be 93% from 1980-85, and 71% from 1985-2002. In a much more detailed assessment, Junginger et al. investigated the potential for technological learning and cost reductions in Swedish wood fuel supply-chains [23]. This study concluded that the cost of primary forest fuel (PFF) (slash and treetops) decreased following a learning curve from 1975-2003, over nine successive doublings of production, with a progress ratio of around 85%. Specific areas of the supply-chain where cost reductions were observed included: (i) felling costs - increased awareness reduced contamination with rocks and mud; (ii) forwarding costs – increased experience and improved equipment; (iii) Chipping costs – technical improvement and increased reliability of chippers. One interesting observation was that net transportation costs remained stable suggesting that cost reductions may be exhausted in this area.

2.3 Innovation as a systemic process

One of the criticisms of dividing the innovation process into stylised stages has been that it fosters the notion that innovation is a linear process that starts with R&D [7]. The countervailing view is that innovation is a system wide process that transcends changes in technological artefacts to include changes in wider socio-economic structures and institutions [12,47]. This second view holds that the innovation and diffusion process is "an individual and collective act […] the determinants of which are not only found in firms [because] firms are embedded in innovation systems that aid and constrain the individual actors within them" [25]. Systems models of the innovation process are typically conceptualised in terms of components and functions.

Components include:

- actors (firms / innovative entities / agents);
- interactions between firms (linkages / networks); and,
- the context in which the firms operate (institutional framework).

Functions include:

- the creation and diffusion of new knowledge;
- guidance of the direction of search among users and suppliers,
- the supply of resources such as capital and competencies;
- the creation of positive external economies; and,
- the formation of markets [26]

Such models are highly abstract. They have also been criticised for leaving little room for individual agency [27] and for failing to explain the actions of entrepreneurs [28]. Nevertheless, systems models can play an important role in the commercialisation process, for once a systemic failure has been identified it can serve as a platform to argue for public support.

3 PART 2: IDENTIFYING THE NEXT STEPS ON THE PATH TO MARKET

3.1 Methodology

The scope of this investigation was limited to companies that claimed to be developing, commercialising or investing in, technology for the conversion of lignocellulosic biomass to liquid biofuels during the period January 2008 – April 2009. Target companies included those developing catalytic and gasification technologies, in addition to companies pursuing ethanol production via the hydrolysis and fermentation pathway.

Empirical data was obtained from two sources: presentations by companies at specialist conferences and semi-structured interviews conducted using a standardised interview scheme. These sources were supplemented with information gathered from the companies' websites. Gathering information from conferences on the commercialisation of second generation biofuels provided breadth, enabling data on a large number of companies to be collected rapidly, while at the same time permitting questions and discussion. Semi-structured interviews provided depth, enabling a more complete exploration of the subject with more full responses [29] [30,p316]. Combining the information sources had two advantages. Firstly, information gained from conference presentations helped inform the development of the interview scheme. They also provided a means of evaluating its completeness, as pertinent issues that arose during company presentations could be indentified, included in the scheme and followed up in subsequent interviews. Secondly, attending conferences provided a means of identifying and making contact with potential interviewees.

The structured interview explored four themes.

- What was company's current experience with second generation biofuels, the rationale behind their current strategy, and the applicability of current experience to LE?
- What would persuade companies to investigate further, to invest in LE technology and, if they were to make an investment, how would they go about it?
- How might the commercial opportunities be realised?
- What else needs to be done, and who needs to do it?

Specific questions were then grouped under each of these themes. The final interview scheme is shown in Figure 3. To encourage free discussion, the interviewees were offered the opportunity to remain anonymous; around half elected to take this option.

3.2 Limitations, subjectivity and bias.

In seeking to explore the path to market for LE through the perspectives and opinions of existing companies, a number of assumptions are implicit: that companies can be identified, that their opinions and decisions can be accurately discerned, and that generic lessons can thereby be induced. Other limitations and potential sources of bias which need to be borne in mind in the subsequent analysis include the following issues.

- Companies pursuing second generation biofuels inevitably seek to cast their activities and decisions in a positive light. One of the prime motivations for self promotion is to seek investment, participation in conferences may also form part of a companies political, or lobbying strategy.

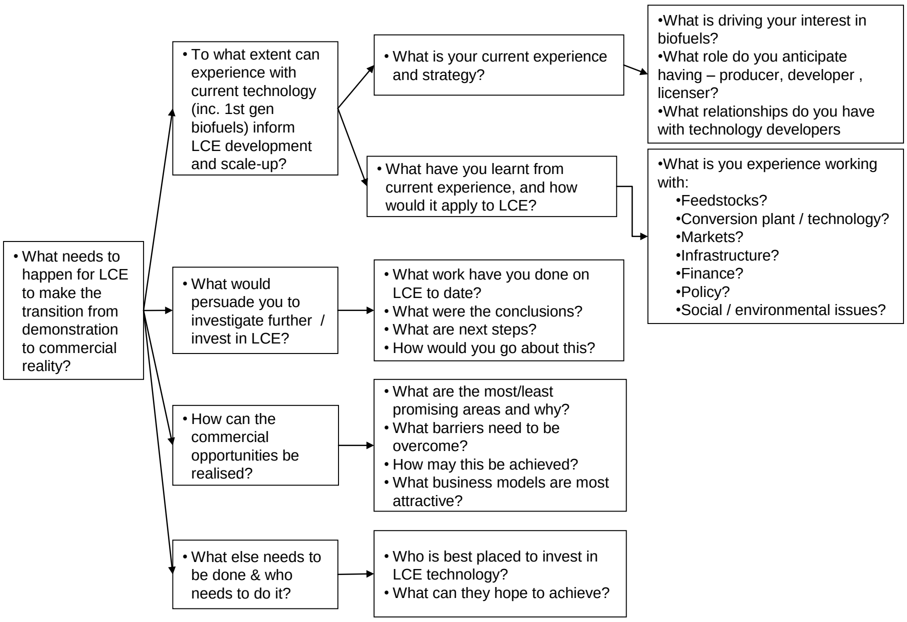


Figure 3: The path to market: research question breakdown, interview structure and questions.

- Companies that have looked at second generation biofuels and decided to take no action are invariably harder to identify.
- Commercial confidentiality limits what companies are willing to disclose. As a technology moves closer to market, less information is typically forthcoming.
- A company's intentions and strategy are dynamic, they will be adapted by the company to reflect the changing environment. During 2008/9 the policy context, investment environment, and oil price have all changed dramatically.
- The focus on companies as the principle market actors is also limiting. It may be argued that policy makers have a central role in setting the context and that environmental lobby has been pivotal in setting the political agenda.

The methodology is thus inherently subjective and can only provide a limited snapshot of a moving picture. Despite these limitations and caveats, the empirical data gathered is nonetheless informative, and in the absence of techniques for perfect forecasting, provides a basis for critical discussion.

3.3 Categorising and targeting companies and interviewees

A stakeholder mapping exercise, undertaken within the NILE project identified over 120 companies developing lignocellulosic biofuel technology globally**.** These companies are very diverse, not only in terms of their size, capabilities, and the part of the supply-chain in which they operate, but also whether second generation biofuels is a peripheral or core activity. In order to target a representative spread of company types and interviewees across the supply-chain, a classification scheme was developed, based on one used by one of the independent oil companies interviewed. This scheme makes a direct analogy between biofuel and fossil fuel supply-chains. Accordingly, companies are classified as either *upstream*, *mid-stream*, *downstream*, or *investor*, as follows:

- *upstream* companies are defined as those that focus on feedstock supply, logistics and the development of enabling technologies such as new plant varieties and germplasm;
- *mid-stream* companies are those that focus on the conversion process including pre-treatment, biochemical and thermochemical pathways as well as the development and supply of enzymes;
- *downstream* companies are those that focus on trading, blending and distribution, traditionally a role played by the oil companies; and,
- *investors* may be independent – banks, venture capitalists, etc. – or they may include the companies themselves, seeking to either expand their own capabilities or make strategic investments outside their core area of expertise.

Interviewees are listed in Table 2.

Interviewee details/label	**Company description and classification** (U=upstream; M=mid-stream; D=downstream; I=investor)
Simon Wilcox CEO Greenspirit fuels 13-12-07	(M) Greenspirit Fuels (GSF) A farmer owned company specialising in grain storage and trading. GSF was set up with the aim of pursuing alternative markets for grain
Claus Hirzman- Project Manager Mondi Business Paper 19-2-08	(U) Mondi Business Paper a leading manufacturer of high quality low-chlorine and chlorine-free paper
Dr Steven Martin Associate R&D Director TMO Renewables 22-2-08	(M) TMO Renewables is a venture capital backed, pre IPO, company, developing novel LE technology using thermophilic micro-organisms
IOC#1 24-6-08	(D) An international oil company (IOC) The interviewee was a member of the bioenergy team.
Jan Lindstedt CEO Sekab Industrial	(M) Part of the SEKAB Group, Sekab Industrial Development seeks to

Development 25-6-08	commercialise research on lignocellulosic ethanol
IOC#2 25-6-08	(D)) An international oil company (IOC) and major European fossil and biofuel trader and distributor. The interviewee was director responsible for assessing new business ventures including biofuels
Michael Deutmeyer Managing Director CHOREN Biomass 8-7-08	(M) CHOREN a German gasification company
Harry Boyle Lead Analyst, Biofuels New Energy Finance 8-1-09	(I) New Energy Finance (NEF) is a specialist provider of information and research to investors in renewable energy, low-carbon technology and the carbon markets
IOC#3 16-1-09	(D) An international oil company (IOC). The interviewee was a member of the bioenergy team.
Ethanol marketing manager 16-1-09	(M) Ethanol marketing manager at a leading European ethanol blender and distributor

Table 2: Individuals and companies who participated in a semi-structured interview

Comments made during interviews, where permission was given, are attributed to the interviewee. Where an interviewee elected to remain anonymous, the name of the interviewee and company are disguised. Comments made in a public forum during presentations are attributed to the person who made the presentation. It should be emphasised in general that the views expressed should be taken to represent the views of the individual and not the company.

4 RESULTS, SYNTHESIS AND DISCUSSION

This section gathers together the views expressed by companies, investors and other interested parties during interviews and presentations. These views are grouped in a structure that loosely reflects the interview structure: motivations for investing in biofuels, investment strategies and business model, and insights from experience working with LE supply-chains. Assembling and comparing these different perspectives, however, it becomes immediately apparent that in a number of areas there is significant overlap that verges on consensus. It is useful to present these here as they can be taken as a common basis for the synthesis that follows:

- the second generation biofuels industry is embryonic, there is no dominant technological paradigm, and it is unclear whether a dominant paradigm will emerge over the next 5-7 years;
- access to feedstocks and the problems inherent in demonstration and scale-up present a significant challenge to the future development of the industry; and,
- public policy and the availability of private finance for technology development are inextricably linked.

The following viewpoint, expressed by the president of a joint venture between Dupont and Danisco that was set up to develop cellulosic biofuels, echoes many of these sentiments, and can be taken to be broadly representative:

"The industry is still very much in its infancy. Someone needs to come to the table with an economically viable solution. And that will not be just a technical solution; it needs to go all the way back to the field. To ensure that everyone is making a return along the value chain, and that throughout the entire value chain people are able to make a justifiable return for the risk they are taking and the alternative options that they are giving up.

If you have a technology package that is ready to go, the question is – how does that package fit within the marketplace? And the key to that marketplace is the cost of feedstocks and the price of ethanol. You have to make sure the cost of biomass is low enough whilst is still providing a return to growers. To keep the cost of biomass low we will need incentives across the value chain." [31] (Skurla, J., president, Dupont Danisco Joint Venture).

4.1 Motivations for investing in LC biofuels

What motivates companies? Examining the strategies and actions of companies pursuing lignocellulosic biofuels reveals three broad motivations for interest and investment: the potential for a large market and rapid market growth, the potential to increase the profitability of existing operations, and the potential to profitably exploit existing capabilities. For larger companies the size of the market is a fundamental consideration. There are divergent views as to how the market will develop, but the key point is that it is expected to be sufficiently big to make strategic investments worthwhile, even for the larger companies. A view succinctly expressed in relation to the paper company UPM's decision to pursue biofuels:

"The strategic question for UPM is how to make a profitable and significant business: i.e. on some time horizon there needs to be a prospect of a 1bn turnover business… even the most pessimistic estimates put the market for biofuels at ~100bn euro by 2020." [32] (Sohlstrom, H., Executive vice president new businesses and biofuels, UPM).

The size of the market size relative to the size of the company is also an important consideration for the international oil companies:

"You have to look at what we do from the perspective that [we] are a very big company. If something is not big then it has no impact on our scale." (Interview: IOC 1).

For the smaller companies, although the size of the market in relation to the size of the company is unlikely to be a constraint, the potential for a large and growing market to develop is also frequently cited as evidence that pursuing lignocellulosic biofuels is worthwhile.

The prospect of using lignocellulosic biofuels technology to increase the profitability of existing operations appeals primarily to mid-stream and up-stream companies. Existing ethanol producers, for example, describe themselves as motivated to develop and adopt technology that can add value to secondary process streams and residues such as distillers dried grains (DDG), stover and bagasse. This motivation is also demonstrated by their proclaimed actions. Examples of companies seeking technology to convert DDG and agricultural residues include POET, the largest dry mill ethanol producer in the US [33], and Abengoa, the Spanish/American grain-to-ethanol producer [34]. Bagasse is also of interest and, according to the CEO of the Swedish ethanol company Sekab, the co-production of ethanol from bagasse at existing sugarcane plants provides the "lowest and largest of the low hanging fruit" {Carstedt, 2009 #281).

More broadly, however, it can be seen that companies view the production of cellulosic biofuels as means to expand or increase profit margins, rather than an end it itself. The following comment from a UK company specialising in grain storage and seeking to build a conventional grain-to-ethanol plant illustrates this point:

> *"The starting point was how can the value of our existing business be enhanced, not how can biofuels be provided." (Interview: Wilcox, S., CEO, Greenspirit fuels).*

Although not primarily interested in lignocellulosic biofuels, the same company had nevertheless considered the role that they might play in the future:

> *"Incorporating lignocellulosic materials [into an existing grain to ethanol plant] would be part of a risk mitigation strategy: broadening the feedstock base and reducing exposure to volatile grain markets. Essentially it would be good insurance against peaks in the grain market." (Ibid).*

The paper company Mondi, although far bigger and operating in a completely different market, has similar priorities, emphasising the need to maximise the overall profitability, irrespective of the technology used and even the products produced:

> *"We need to look at what is the most value we can add to our feedstocks. Essentially we don't care whether we make ethanol or paper. The only real criterion is profitability. We are not wedded to any particular production process." (Interview: Hirzman, C., Mondi business paper).*

A last illustration of this point is provided by Dong Energy. Dong is a Danish electricity utility that co-fires straw in coal fired power plant and began developing a straw-to-ethanol technology after experimenting with washing straw in order to reduce boiler fouling. The motivation in their case was not the production of ethanol but the production of a solid biomass product that could be co-fired more easily:

> *"In the US the talk is all about ethanol, but the production of lignin is the main driver for Dong" {Morgen, 2009 #282} (Morgen, C., Senior manager business development and marketing - Inbicon (Dong Energy)).*

The ability of downstream companies to use biofuels to increase the profitability of existing retail operations is more limited, and in a competitive market would ultimately depend on the arbitrage between the price of biofuels and the price of gasoline. Nevertheless, opportunities for arbitrage may arise:

> *"Currently [January 2009], ethanol is above the gasoline price, but over the summer [2008], when the oil price was very high, oil companies were going beyond the mandates and selling a 5% blend because ethanol was priced low compared to gasoline." (Interview: Ethanol marketing manager).*

It also should be borne in mind that the market for ethanol is far from competitive and is influenced by political decisions, blending mandates, restrictions on the maximum proportion that may be blended etc. Selling ethanol may therefore be profitable, even if the price of ethanol is greater than gasoline.

The potential to exploit existing capabilities, and in particular knowledge, appears to be a key feature in the decision making of smaller companies for whom the development and application of technology forms a significant part of their raison d'être. An example of such a company is the German gasification company, Choren:

> *"The starting point of the company was gasification – the founders had knowledge of this technology and considered it one of the good ways of converting biomass. In this sense the company was technology driven rather than selecting the best approach from a range of options." (Interview: Deutmeyer, M., Choren).*

A large number of the mid-stream technology developers might reasonably be viewed as similarly technologically driven. This focus may be deliberate – ring fencing potentially disruptive innovation in a subsidiary company is one of the management strategies proposed in the innovation literature [5]. Alternatively, it may simply reflect the technological capabilities which were available when the company was founded. In the UK, for example, there are three companies focusing on the application of thermophilic micro-organisms to biofuels: TMO Renewables, Green Biologics and Biocaldol. These companies share a common heritage and can trace their origins to the dissolution, in 2003, of a university spinout company called Agrol Ltd. Since going their separate ways, these companies have adopted divergent strategies: TMO is focussed on the production of ethanol from a broad range of lignocellulosic feedstocks [35], Biocaldol is focused on the production of ethanol from hemi-cellulose sugars [36], and Green Biologics is focussed on improving the acetone-butanol-ethanol (ABE) fermentation [37]. All three companies, however, remain focussed on thermophiles. In line with what might be predicted from the strategic management literature, their current strategic direction appears to have been largely determined by their initial capabilities.

What motivates investors? Whereas companies appear to derive motivation from their existing operations and capabilities, financial investors are motivated primarily by the potential for rapid market growth and are technologically agnostic. The amount of money that financiers are prepared to invest depends on their assessment of risk: the greater the risk, the less money will be forthcoming and the greater the return they will demand. What distinguishes an investment in a new production technology from a similar investment in an established technology is the level of technical risk. Venture capital (VC) investors are the finance providers most willing to accept this risk, but their acceptance comes at a price: they demand a higher return than other investors. Moreover, the size of a typical VC investment is small when compared to the investment required to build a pilot plant or demonstration facility:

"VCs don't care whether the company makes chemicals or fuels provided that it has potential to grow. The fuel market is interesting because it is protected by policy. There are no equivalent policies for green chemicals.

Investors are shy of demonstration projects. They are big and expensive. [Instead] Cleantech VCs have focussed on the biotech side: new bacteria, enzymes, fermentation processes etc. These are low cost companies, not much more than three scientists and a lab. Lab-scale technologies can also be sold on to the pipeline in order to realise an earlier return." (Interview: Boyle. H.,, lead analyst, biofuels, New Energy Finance)

For the venture capital investors, more important than picking a winning technology is picking a winning team:

"technology is a commodity, what is more important is the ability to have the right kind of relationships. This is key." [38] (Baruch, T., CMEA ventures).

Advocates of specific technology may also be viewed with suspicion:

"In general technology providers are enthusiasts. Take BlueFire Ethanol for example, they are using concentrated acid technology and have better acid recovery process. They tell you that they are getting the feedstock for free; consequently the conversion process looks economic. But ultimately biomass will become a commodity." (Interview: Boyle, H., lead analyst, biofuels, New Energy Finance)

4.2 Strategies for investment and business development

Strategies for investing in cellulosic biofuels. The strategic-management innovation literature suggests that a company's choice of strategy for investing in LE – whether it should invest, how it should invest etc. – will be determined by the resources and capabilities that it has at its disposal. It is perhaps unsurprising, therefore, that the disparity in the resources available to the different companies interested in LE gives rise to a range of strategies. These can be crudely characterised as *building a portfolio, picking a winner* or *keeping a watching brief*.

The oil companies are large enough to take a strategic view of both the market and the technology and build a portfolio of options. Like the financial investors they are demonstrably technology agnostic. Shell, for example, has invested in five companies spanning a range of technologies: Iogen – cellulosic ethanol via the enzymatic process; Choren – two stage biomass gasification combined with Fischer Tropsch synthesis; Codexis – a platform technology for enzyme production; Cellana – a join venture looking at marine algae; Virent Energy Systems – catalytic conversion of sugars to gasoline [39]. British Petroleum (BP) have also adopted a portfolio approach as part of a proclaimed strategy to "develop an upstream biofuels business" [40]. Investments made by BP include joint ventures with Verenium to develop commercialize LE and with Mendel Biotechnology to develop cellulosic bio-feedstocks [41].

The paper companies, situated at the other end of the supply-chain to the oil companies, have a clear focus the efficient use of their existing resource base but are similarly open minded when it comes to identifying the most appropriate technology. They are also large enough to hedge their bets and invest in a technology portfolio. UPM for example, are pursuing three biofuel concepts: gasification of forest residues followed by Fisher Tropsch, pyrolysis of forest residues to produce bio-oil, and the production of ethanol from recycled fibre. [32].

The *build a portfolio* option is unlikely to be available to smaller companies. These companies are limited in the strategies they can adopt by the resources that they can deploy. They are effectively forced to try and pick a winning option which will deliver near term results, even though they may be attracted to technologies they are unable to pursue:

"TMO's proposition is to offer a thermophilic organism, process design, and process guarantee. Consolidated Bioprocessing is a wonderful vision, but we would run out of money long before we got there. Our work needs to generate a revenue stream as early as possible." (Interview: Martin, S.,, associate R&D director, TMO Renewables)

Notably, TMO's original strategy was limited to the provision of a thermophilic ethanologen but was modified to better reflect potential customers' demands:

"We spoke to potential customers in the USA and no one was interested in the organism alone. This is because the system - pre-treatment, hydrolysis, fermentation is so interdependent. Consequently, TMO's proposition has moved from licencing the organism to the whole system." (Ibid)

The *keeping a watching brief* option is a low cost strategy, but is not entirely passive. It requires a minimal investment in the skills and information needed to make an informed decision. There is also the risk that the cost of catching up may become prohibitive:

"Essentially we wish to make an informed decision whether to be an early adopter, early follower or late follower. One option is to secure privileged access to feedstock and wait. The wait option gives insight on disruptive technology, but there is always the risk that the market settles. We need to position ourselves first." (Interview: Hirzman, C., Mondi business paper).

Another reason to keep a watching brief is because existing companies lack experience:

"To start such a complex, large, process with young engineering companies is too risky. We have had problems before with biodiesel plant; the small companies are ambitious, but they don't have the skills and experience to deliver. For [us] to invest we would need to see big, established, engineering companies offering proven, turnkey plant designs. For example Lurgi or UOP – who are the major engineering companies in the fuels business. Currently there are no engineering companies operating on a sound basis who can offer turnkey plant and tell us how well it can perform. Look at how much the US has spent in this area and no plants have been built. The industry lacks robust process designs but also the ability to handle the money." (Interview: IOC#2)

Business models. For a company developing new technology for the production of lignocellulosic biofuels there are three principal business models: becoming a *technology supplier*, a *component supplier*, or an *owner operator.* The *technology supplier* model is a licensing model in which the technology developer offers a licence to a construction or production company in return for a royalty based on the ethanol produced. A company adopting the *component supplier* model would aim to manufacture and sell key components to other operators and plant developers. The *owner operator* model assumes that the company builds, owns and operates a production facility, selling ethanol (or other biofuels) and related products.

The advantages and disadvantages of each approach have been considered by Dong Energy, in relation to the commercialisation of their own straw-to-ethanol process, but they are broadly applicable:

> *"The advantages of becoming a technology supplier are global reach, scalability, and the potential to pursue aggressive market expansion. The disadvantages are that success is contingent on capturing market share; there is also a greater risk of IP infringement. This is our preferred approach.*
>
> *The advantages of becoming a component supplier is the potential for global reach and the ability to protect proprietary intellectual property. The disadvantage is that market growth is dependent on the expansion of the customer base, over which we, as a supplier, would have no control.*
>
> *The owner operator model is relatively low risk and has the potential to be profitable with a small market position. From the developer point of view, however, there are a number of disadvantages: limited scalability, slow roll-out, revenue streams limited by capacity, and high investments in infrastructure. It may also be difficult to expand globally." [42] (Morgen, C., Senior manager business development and marketing - Inbicon (Dong Energy).*

The early development of corn to ethanol plants by farmers' co-operatives in the US essentially followed the owner operator model. Hybrid models are, of course, also possible and may form the basis of a business strategy. For example, a company may seek to become an owner operator in its domestic market and a technology supplier in export markets:

> *"Our aim is to become a supplier of technology worldwide. In some markets e.g Africa, EU, we would be a turnkey plant provider. In others we would licence the technology." (Interview: Lindstedt, J., Sekab)*

Strategic partnerships. Forming a strategic partnerships with another company is another prominent strategy. Biogasol, for example, claim that their approach is to "work in partnership" and have secured relationships with the sugar producer Tate and Lyle and the conventional ethanol producer Pacific Ethanol [43]. Virent similarly claim that their "commercialisation strategy is to collaborate with tier-1 partners: Honda and Shell" who along with Cargill are leading investors in the company [44]. The oil majors, BP and Shell have a number of other partnerships which have already been discussed.

Forming such a partnership has clear advantages: it can bolster the confidence of customers and is also a pragmatic approach to working with the complete supply chain, illustrated by this perspective from Verenium, a mid-stream technology developer:

> *"[Starting to build a commercial facility] for a company like ours is the moment of truth where you come face to face with the realities and complexities of such an undertaking. You are really talking about the development of a whole supply chain which starts with the economics and goes right through to the development of the project itself; along with the technology, how to operate it and deliver your product into the market". To work on that entire supply-chain is far too much for a single company to do on its own and that is what led us to a partnership strategy." [45] (Riva, C., President and CEO, Verenium)*

4.3 Insights from companies' attempts to commercialise ethanol

Work being undertaken by companies to commercialise LE encompasses all the technical stages of the supply-chain, but must also consider the interactions with the realms of policy and finance. This section describes some of the most prominent perspectives expressed by companies, grouped according to the stages of the LE supply-chain – feedstock supply, conversion, etc.

Feedstock supply. Obtaining large quantities of low cost biomass that is of acceptable quality is one of the principle problems facing the scale-up and commercialisation of cellulosic ethanol and biofuels more generally. This issue is widely recognised:

> *"The key to a successful project is securing feedstock at a reasonable price… new entrants will struggle unless they can lock in a feedstock price." [46] (Peara, T., Alternative Energy Finance}*

> *"When we look at the economics, the biggest problem is the cost of biomass." [31] (Skurla. J., President, Dupont Danisco Joint Venture}*

> *"To scale up the technology to a commercial scale, first and foremost you must be sure of your feedstock base, you cannot focus on the technology alone" (Interview: Deutmeyer, M.,, Choren)*

Those companies that have access to resources also recognise the competitive advantage that this confers:

> *"We consider that the power in the market is in the raw material side. Our principal advantage is our privileged access to high volume low cost biomass." (Interview: Hirzman, C., Mondi Business Paper)*

Solving the feedstock supply issue has yet to be demonstrated in practice. One strategy is to limit the production of LE to sites where readily accessible feedstocks are available, for example co- products from existing processes:

"The first proposition is a side door plant – next to an existing grain to ethanol plant using DDG, and potentially the fibre fraction if this is separated out." (Interview: Martin, S., associate R&D director, TMO Renewables)

This option, however, limits the scale of production. Securing access to waste materials may also prove problematic:

"Waste materials are available, e.g agricultural residues, but the price will increase if suppliers perceive that they are valuable to you. Farmers are quite content not to sell if an agreement on price cannot be reached" (Interview: Deutmeyer, M., Choren).

The international oil companies are interested in large scale production and see strategic partnerships and vertical integration as the way forward:

"The role of strategic partnerships will become critical in the case of advanced technologies using dedicated energy crops, since this requires farmers to move away from producing commodity agricultural goods that have a number of potential markets to crops that have only one market and probably in many cases only one customer (due to logistic issues). Therefore vertical partnerships will be a key means to mitigate / diversify this business risk." (Interview: IOC#1)

"Our view is that biofuels are very much an integrated play. You have to look at the chain from feedstock supply through to product" (Interview: IOC#2)

The Verenium Corporation is one of the companies pursuing this option in partnership with British Petroleum.

"Ultimately we are talking about taking very large quantities of biomass. How that translates for us on the US Gulf cost is energy crops where we lease the land and contract for the supply so we are able to control the energy crop resource – it translates from our analysis into the lowest cost, reliable, long term feedstock supply we can get in the US" [45] (Riva, C., President and CEO, Verenium)

In the absence of political constraints, considered further below, there is a general consensus that the source of the biomass should determine the location of the plant:

"If you look at the volumes of biomass required. Then Russia and Canada are interesting locations. We don't believe in transporting biomass." (Interview: Lindstedt. J., Sekab)

"At the commercial scale – We have an idea of the scale required. Approx 400,000 air dry tonnes of chips ~ 65,000 tones of ethanol. This is the same order of magnitude as a pulp mill. The most important thing is the biomass cost, and this suggests we should locate in South Africa or Russia." (Interview: Hirzman, C., Mondi Business Paper).

Transport of biomass, however, is possible and this could potentially lead to the commoditisation of biomass feedstocks, which would increase exposure to market volatility and reduce further the ability of producers to lock-in a profit margin. Views diverge about how severe this risk is in practice:

"Arbitrage means that price gaps between substitutable products [oil and biomass] will tend to close. Nevertheless, currently a gap exists and I think that it can be maintained. For example: pellets are available at €120-180/ton but contain the equivalent energy of €300 of fossil fuel. I.e. there is a multiple of two. Conversion technology needs to be developed – there is the potential to use a huge amount of pellets. The real sleeping giant is co-firing. Coal costs ~€220/ton, and if you have to purchase CO_2 certificates too, pellets are the same cost per GJ." (Interview: Deutmeyer, M., Choren).

"I don't think that gap between oil price and biomass can be sustained. There are too many alternative uses for bioenergy: pellets, electricity, etc. The feedstock price will inevitably be connected to the oil price. It will however take time to build up capacity of other technologies." (Interview: Lindstedt. J., Sekab)

"Whether you can lock in a profit margin, or not, depends upon how robust the process is and how diversified the feedstock base can be. If you can only use premium quality biomass then you are likely to run into problems. If you can use a range of biomass qualities, sourced from multiple locations, then a profit margin could be maintained.

It is worth making the comparison with an oil refinery. A refinery is designed for a specific grade of crude oil, and cannot easily be adapted to use, for example, sour crude. Biomass is even more diversified, and processes that rely on fermentation will be especially sensitive. A mixture of feedstocks cannot be handled with existing processes." (Interview: IOC#2) .

Although a strategy of diversifying the feedstock base is attractive in theory, it is worth noting that it may not be a practical option unless the plant is located close to a port. A conversion plant based in a grain growing area and designed to use agricultural residues, for example the mid-west United States, is unlikely to be able to procure softwood at a reasonable price, even if it were technically able to use it.

4.4 Conversion: demonstration, scale-up and integration

The need to demonstrate the conversion technology, scale-up production capacity and integrate production with other facilities, are readily identified as common strands of companies' technology development strategies. Demonstration and scale-up are closely related, as unless you can demonstrate that your technology works at small scale, persuading investors to back a larger scale version will be difficult. Integration with other facilities is attractive because it has the potential to reduce the cost of demonstration and may also provide a route to commercialisation.

Demonstration combines both technical and commercial objectives. Both are evident in descriptions of the demonstration stage by two Danish companies: Dong energy and Biogasol:

> *"Demonstration is to reduce the risk and to attract the banks. The purpose of demonstration is technology feasibility, but also the commercial part, what the technology costs, what are the operating costs, and the whole sense of cellulosic ethanol as a business. It is also the basis for providing process guarantees. Right now you cannot go to any technology supplier and ask for a process guarantee."[43] (Langvad, Business development manager, Biogasol)*

> *"What we are demonstrating is a small scale version of the business: a demonstration of the entire value chain. We realised that this was necessary because there is a lot of stuff up and downstream of our core technology. The issue is not to build a demonstration plant without technical problems, but to find the technical problems and fix them." [47] (Morgen, C., Inbicon (Dong Energy))*

Demonstration is most often regarded as one of a series of steps required to attain commercial scale. Verenium describe the need to scale-up gradually and emphasise the importance of learning as you go:

> *"If you are making the leap from a laboratory scale tech and turning it into a commercial project you need to take a certain number of steps to scale-up in a measured and disciplined manner. To take the learnings [sic] from each step and recycle them back into the research.*
>
> *[we have] lab facilities and a small pilot plant in Santiago where results from the lab can be immediately validated at small scale. We also took the step of building a pilot plant in Louisiana which we operated for a couple of years. Then we took the further step of building a demonstration scale plant – sized at 1.4million gallons per year. It allows us test feedstocks, enzymes, process strategies, develop the operating skills and work out some of the feedstock supply strategies. All of this represents a very valuable feedback loop with the research and this is allowing us to make rapid progress in working out a commercial strategy. The next step is scaling up by a factor of 25 – and building a 35 million gallon per year commercial size plant." [45] (Riva, C., President and CEO, Verenium}*

The hands-on experience that working at the demonstration scale can provide is also considered important by the oil companies and other mid-stream technology developers. Both as a means of managing risk and a source of competitive advantage:

> *"It is important not to underestimate how important scale-up is. If you are not intimately involved in the development and scale-up of a process it might look easy, but when you do it, it can turn out to be a lot more complicated. In practice scale up issues can be significant. Not everything scales linearly. As a technologist, demonstration provides a way of checking and learning. It is a prudent way of checking and learning the fine detail.*
>
> *Scale up can be difficult unless you can afford to bring all the skill you need together. Otherwise you may find that you lack a vital part of the picture. Large oil companies can do this. The corollary is that claims made on a small scale are no guarantee of success" (Interview: IOC#3)*

> *"Sekab will be both supplier of technology and use cellulose base technology in its own plants. We will supply our own facilities with the technology first. We believe that developing the technology in our own plant gives us an advantage over competitors. Poet [a US ethanol company] is working on the same basis, aiming to use corn stover and fibre in existing corn to ethanol plant." (Interview: Lindstedt, J., Sekab)*

The combining of commercial and technical objectives at the demonstration stage also poses a risk. If the technology performs less well than anticipated, investors and potential customers may lose confidence. Managing expectations, therefore, is an important part of the commercialisation process. It is notable that the fact that a company is demonstrating its technology tends to have a high public profile, whereas the results of the demonstration tend to be confidential. One major European fossil and biofuel provider, trader, distributor, and potential customer for a turnkey plant, expressed their frustration with the lack of data, progress, and press releases designed to manage their expectations:

> *"Currently there are no engineering companies operating on a sound basis who can offer turnkey plant and tell us how well it can perform. There are a number of demonstration showcases [both in the EU and the US] but for the time being nothing is proven. It is also impossible to find out anything about how the demonstration plants are running, certainly not enough to jump in with an investment. Looking at the publications from Shell, Iogen, etc., it is evident that a large number of improvements are needed to make the conversion process feasible. For example, Iogen have announced that they have produced and sold 180m^3 of ethanol to Shell for evaluation purposes, [but] after more than 5 years of development this is just window dressing." (Interview: IOC#2)*

Integrating LE production with other industrial facilities, e.g. a first generation ethanol plant or a combined heat and power (CHP) unit, provides an opportunity to share utilities, reduce costs and gain vital operational experience with considerably less capital outlay than building a stand-alone plant. Jan Lindstedt, CEO of Sekab's industrial development business, argues strongly in favour of integration:

> *"We don't think that we will have stand alone units. Integration with other facilities will be essential. Many integration options have been proposed, but the principal ones we are considering are: integration with pellet production, with CHP, with first generation ethanol production and, in the longer term, with bio-refineries. Operations that add value to the co-product streams –lignin and biogas – will also be of critical importance." (Interview: Lindsted,. J.,, Sekab)*

The paper company UPM also anticipates that all its biofuel projects would be integrated with existing pulp mills:

"The reasons for integration are as follows:

- *significant savings in investment cost – wood handling, water treatment etc. are already there;*
- *the raw material supply chain is in place; and can be increased in a cost effective way; and,*
- *energy efficiency, opportunities to use excess heat and integrate other material flows. [32] (Sohlstrom, H., UPM)*

The oil companies, however, express divergent views about whether stand alone plant will be attainable. Jacques Blondy, of the French petroleum company Total, believes not:

"It is hard to imagine a scaled up plant working alone. Most today are designed as an add-on to conventional ethanol." [48] (Blondy, J., director of agricultural development, refining and marketing, Total)

But another of the international oil companies believes otherwise:

"We are confident that we can go for big plant. If you envisage cellulosic ethanol having a significant role in future global fuel supply it is worthwhile having the ambition to go for large scale plant. Also, if you have the world stage to say when and where and you are going to produce ethanol, there is a clear opportunity to have large scale facilities." (Interview: IOC#3)

4.5 Retail and distribution

The downstream infrastructure required to distribute ethanol attracts far less comment than the issues of feedstock supply or the conversion process. The general view of the mid-stream and up-stream companies is that this has been shown to work with first generation ethanol and that there are no significant technical problems to be overcome. One of the oil companies, however, voices caution about taking this aspect of the supply-chain for granted:

I wouldn't underestimate any aspect of the supply-chain. There is a risk in assuming that the actual distribution network for ethanol is a trivial investment. It is not. The existing fuel infrastructure has had many million dollars spent on research and development to make it work - it is easy to underestimate the work that goes on in the background. The ultimate success is that no one notices, but for those involved it is a day to day challenge. (Interview: IOC#3)

4.6 Ethanol markets and public policy

Public policy pervades all aspects of the biofuels industry. It underpins both the existing market and the rationale for future investment:

"The reality is that we need the subsidy. Without it there would be no industry"[49] (Plaza, President & CEO, Imperium Renewables

"[The] ethanol price depends not only on the supply/demand balance but the interaction with policies and regulations. The ethanol market is influenced by political decisions, blending mandates, restrictions on the maximum proportion that may be blended etc. Customs tariffs also have a strong influence on the price" (Interview: Ethanol marketing manager)

Arguably, however, it is the propensity to change that causes the greatest concern:

"...clearly oil and feedstock prices fluctuate, but the worst factor is policy change. Regulatory changes are fast and hard to predict" (Ibid)

"Investors know that everything relies on the politics and could change overnight. They need to be convinced that there is a stable interest. For this reason the EU 10% goal is important. It sends a signal that the commitment is genuine." (Interview: Lindsted, J., Sekab)

The level of policy support not only determines whether investments are made, but also where they are made. The introduction in the US of the Farm Bill and the Renewable Fuel Standard (RFS) has made the US a far more desirable location for investment than the EU. This is reflected in companies' strategies for scaling-up and commercialising their technology, and in decisions about whether to take an active role in the market at all:

"Our attitude towards lignocellulosics until about 18 months ago was, quite frankly, that it all looked quite uncertain: there were many pathways, we would take a watching brief, perhaps come in and act as an consolidator or aggregator or when the time was right. The RFS changed that. The RFS made it clear that there was going to be a lignocellulosic market in America from next year. That meant we moved from being happy observer and followers of a technology to a firm that decided it needed to be market leaders because we could see progressive legislation pointing the way." [50](New, P., Head of Biofuels, BP)

"We are focussing on the US because it is more favourable from a policy point of view…" [31] (Skurla, J., President, Dupont Danisco Joint Venture)

"If you want to do something in this field you had better not be in Europe, you had better be in the US." [51] (deBont, J., R&D Manager, Royal Nedalco)

Financial investors also recognise the importance of choosing the most favourable policy regime:

"if you are looking to get new tech funded, then establish a US research subsidiary and go to the States" [46] (Peara, T., Alternative Energy Finance)

"The name of the game is to structure the finances to tap into public sector funding sources" [52] (Gilmore, R., GIC Trading).

A more detailed critique of the policy environment in the EU relative to the US, is provided by Jan de Bont from Royal Nedalco. He identifies a range of policy hurdles, some general, and some specific to their own wheat bran-to-ethanol technology, but likely to be pertinent to all developers planning to use genetically modified organisms:

> *"In the EU there are all sorts of problems whether you are looking at first or second generation feedstocks:*
>
> - *free trade – Brazilian alcohol can land in Rotterdamn and there is no restriction on imports;*
> - *no EU legislation supporting the production of second generation ethanol –all alcohol is the same; and,*
> - *the legislation surrounding GMO's is also very restrictive.*
>
> *In our case we want to use wheat bran which contains protein [as a co-product] EU legislation says that you cannot use this for feed. You can apply for a permit but this takes 5/6 years and costs several million Euro. You just can't do it.*
>
> *There are two GMO issues. The first is production – which is not too much of a problem. The second is what do you do with the protein?. You cannot sell it, so you have to make biogas, which is difficult because there is a lot of ammonia which is an inhibitor to biogas. So, your valuable protein, not only are you losing it but it is even difficult to convert into biogas." [51] (deBont, J., R&D manager, Royal Nedalco)*

4.7 Finance

Obtaining finance is essential if companies' plans to develop LE technology are to be realised. At the best of times financing a project with a high level of technical risk is difficult, and the financial crisis that began in late 2008 has served to increase uncertainty. The investment perspective is concisely summarised by Don Roberts from CIBC world markets:

> *"Investments in the bio-energy sector are driven by four key variables:*
>
> - *the price of oil (the main substitute);*
> - *the price of the feedstock (often 50% or more of the cost of production);*
> - *the conversion technology; and,*
> - *regulations the stimulate demand.*
>
> *Investors hate uncertainty…..and at present, all four of these variables are in a state of flux." [53] (Roberts, D., Managing Director, CIBC World Markets).*

The collapse in the price of oil has also affected the first generation biofuels industry, and in early 2009 around 20% of the U.S. corn ethanol capacity was reported to be idle [54] This idle capacity has the potential to overhang the market and depress the ethanol price when the market picks up. Experience with first generation ethanol has also educated financiers about what to look for, and in particular the dangers of commodity risk:

> *"Many lenders are out of the market due to losses on 1st generation ethanol – they won't touch anything labelled ethanol or biodiesel. No one wants to take the commodity risk – so unless you can hedge this you wont get finance" [55] (Peters, J., Managing Director: Project Finance, TD Bank N.A.).*

Despite this grim picture, a number of commentators express optimism. There is an expectation that oil and commodity prices will begin to rise in the next two years and that this will positively affect the economics of cellulosic ethanol [56]. Government incentive schemes are also expected to play a key role [57]. In particular it is anticipated that Governments will play a stronger role in promoting "good" feedstocks and banning "bad" ones [58] In the short term at least, the availability of finance and public policy goals and incentives, appear inextricably linked.

5 CONCLUSIONS

Insights that may be drawn from review of innovation theory presented in the first part of this paper include the following points.

- The path to market for LE is inherently speculative. Innovation theory helps frame some of the strategic choices facing companies developing LE technology, but neither the extent nor the rate of technological diffusion (substitution) can be predicted on the basis of historical data.
- Although not possible to predict the rate of technological diffusion, general lessons from past experience can be identified. In particular, there is a general trend that the greater the scale, infrastructure requirements and technical interdependence, and the lower the relative advantage over the incumbent technology, the longer it will take for the technology to become established. Applying this to LE suggests that the diffusion of LE technology will be a slow rather than a fast process.
- LE is still at the *innovation* stage, although it appears to be entering the *niche market commercialisation* stage. I.e. it is still undergoing applied research and development and the market share is zero, but investments in niche applications and field projects are being made.

The synthesis of companies' and investors' experiences and strategies presented in the second part of this paper paints a mixed and changing picture. But, returning to the overall objective, what can it tell can it tell us about the path to market in the short term?

Many of the companies pursuing LE (and other biofuels) are at – or at least claim to be at – a similar stage: one where they need to demonstrate their technology at intermediate scale and make the leap to a first commercial plant. This supports the assertion that the next step on the path to market is technology validation and demonstration. Yet the fact that companies (and investors) with the resources to do so are adopting a portfolio approach suggests that a winning technology has yet to emerge. Moreover, even if there were such a winning technology, the diversity of feedstocks and options for integration with other facilities makes it unlikely that it would fit all applications. Convergence on a small number of routes or technologies must therefore be considered unlikely.

Yet, even without technical convergence it is possible to identify elements of common practice, if not best practice, for demonstration and scale-up. This includes:

- prioritising access to feedstocks;
- being aware of logistics for both raw material and by-products;

- developing the technology with a full scale plant in mind;
- being conservative with scale-up, ensuring that lessons are learnt at small scale and employed at large scale;
- valuing hands on experience as source of competitive advantage;
- integrating demonstration projects with other facilities to reduce the cost and lower the risk;
- pursuing strategic partnerships, to pool knowledge, mitigate risk, but also to demonstrate credibility to investors and future customers who might be wary of working with a small company; and
- applying reasonable measures to get public funding, including choosing the most favourable policy regime.

Running counter to the suggestion to be conservative with scale-up, of course, is the need to generate and maintain momentum and to secure the next tranche of investment before the cash runs out. The demonstration stage, as we have seen, is expensive. Taking a cautious approach to scale-up may be less risky, but it will also be more costly.

Another development that may be anticipated is that as experience increases, clusters of interest might emerge, based around specific resources and applications. The formation of strategic alliances is evidently a preferred strategy for companies irrespective of their size. The cementing of these partnerships may make it difficult for late entrants to access the best technology and resources.

Europe is currently perceived as far less attractive a destination for the first commercial plants than the US. This could change, but large scale public initiatives would be required. In the immediate term, therefore, developments in Europe are likely to be limited to early stage demonstration, and potentially small integrated facilities.

The number of demonstrations that are planned globally is encouraging and holds out the prospect of learning, over the next few years, what works and what doesn't. Intrinsic in learning what doesn't work, of course, is the prospect that that some of the proposed demonstration plants will fail. Ultimately it should be borne in mind that transport fuel, even at the elevated prices seen in mid 2008 is a low cost commodity. The cheapest and most robust technologies will ultimately be the most successful.

Nothing in the analysis suggest that practical paths to market do not exist. On the contrary, there are an abundance of options, many of which are being actively pursued. The number of companies pursuing second generation biofuels is also testament to the conviction that commercial opportunities exist. The next few years promise to be an exciting and revealing time for biofuels and cellulosic ethanol.

6 ACKNOWLEDGEMENTS

The authors are grateful to the interviewees for their time and insights. We gratefully acknowledge the support provided by the European Commission Framework Programme 7, through their sponsorship of the New Improvements in Lignocellulosic Ethanol (NILE) project. Contract number: 019882. Website: www.nile-bioethanol.org.

7 REFERENCES

1. Grübler, A., N. Nakicenovic, and D.G. Victor, *Dynamics of energy technologies and global change.* Energy Policy, 1999. **27**(5): p. 247-280.
2. *Proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*, in *COM(2008) 19 final*.
3. Schumpeter, J.A., *The theory of economic development* 1934, Cambridge, M.A.: Harvard University Press.
4. Freeman, C. and C. Perez, *Structural crises of adjustment.* in Stenzel 2007, 1988
5. Christensen, C.M., *The innovator's dilemma*. 1997, New York: Harper Collins.
6. Berkhout, F. and A. Gouldson, *Inducing, shaping, modulating: perspectives on technology and environmental policy*, in *Negotiating Environmental Change*, F. Berkhout, M. Leach, and I. Scoones, Editors. 2003, Edward Elgar: Cheltenham,. p. 231-259.
7. Foxon, T.J., *Inducing innovation for a low-carbon future: drivers, barriers and policies: a report for the Carbon Trust*. 2003, Imperial College Centre for Energy Policy and Technology: London.
8. UNEP Collaborating Centre on Energy and Environment: RISØ, *Assessment of the commercialisation of selected sustainable energy technologies, products and services: solar cookers* United Nations Environment Programme (UNEP).
9. Cyert, R.M. and J.G. March, *A behavioral theory of the firm*. 2 ed. 1992, Oxford: Blackwell Publishers.
10. Nelson, R.R. and S.G. Winter, *An evolutionary theory of economic change*. 1982, Cambridge, Massachusetts: Harvard University Press.
11. Christensen, C.M. and M. Overdorf, *Meeting the challenge of disruptive change.* Harvard Business Review, 2000. **78**(2): p. 66.
12. Stenzel, T., *The diffusion of renewable energy technology: interactions between utility strategies and the institutional environment*, in *Centre for Environmental Policy*. 2007, Imperial College London.
13. Penrose, E., *The theory of the growth of the firm*. 1959, London: Basil Blackwell.
14. Chandler, A., *Strategy and structure*. 1962, Cambridge, MA.: MIT Press.
15. Mintzberg, H., *The strategy concept I: five Ps for strategy.* California Management Review, 1987. **30**(1): p. 11.
16. Porter, M.E., *The technological dimension of competitive strategy*, in *Research on Technological Innovation, Management and Policy*, R.S. Rosenbloom, Editor. 1983, JAI Press: Greenwich, CT. p. 1-33.
17. Burgelman, R.A. and R.S. Rosenbloom, *Technology strategy: an evolutionary process perspective*, in *Research on technological innovation, management and policy*, R.A. Burgelman and R.S. Rosenbloom, Editors. 1989, JAI Press,: Greenwich, Conneticut. p. pp. 1-23.
18. Arrow, K.J., *The economic implications of learning by doing.* The Review of Economic Studies, 1962. **29**(3): p. 155.
19. Wright, T.P., *Factors affecting the cost of airplanes.* J. Aeronautical Sci, 1936. **3**: p. 122-28.
20. Argote, L. and D. Epple, *Learning curves in manufacturing.* Science, 1990. **247**(4945): p. 920.

21. McDonald, A. and L. Schrattenholzer, *Learning rates for energy technologies.* Energy Policy, 2001. **29**(4): p. 255-261.
22. Junginger, H.M., *Learning in renewable energy technology development*, in *Faculteit Scheikunde*. 2005, Universiteit Utrecht: Utrecht.
23. Junginger, M., et al., *Technological learning and cost reductions in wood fuel supply chains in Sweden.* Biomass & Bioenergy, 2005. **29**(6): p. 399.
24. Goldemberg, J., et al., *Ethanol learning curve-the Brazilian experience.* Biomass & Bioenergy, 2004. **26**(3): p. 301.
25. Jacobsson, S., *Transforming the energy system--the evolution of the German technological system for solar cells.* Technology analysis & strategic management, 2004. **16**(1): p. 3.
26. Jacobsson, S., *Transforming the energy sector: the evolution of technological systems in renewable energy technology.* Industrial and Corporate Change, 2004. **13**(5): p. 815.
27. Smith, A., A. Stirling, and F. Berkhout, *The governance of sustainable socio-technical transitions.* Research Policy, 2005. **34**(10): p. 1491-1510.
28. Hekkert, M.P., et al., *Functions of innovation systems: A new approach for analysing technological change.* Technological Forecasting and Social Change, 2007. **74**(4): p. 413-432.
29. Eisenhardt, K.M., *Better stories and better constructs: the case for rigor and comparative logic.* The Academy of Management Review, 1991. **16**(3): p. 620.
30. Saunders, M., P. Lewis, and A. Thornhill, *Research methods for business students*. 2007: Harlow, UK, Pearson Eductation Ltd.
31. Skurla, J., *DuPont Danisco Cellulosic Ethanol LLC*, in *FO Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
32. Sohlström, H., *UPM: Next generation biofuels and the new forest industry*, in *FO Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
33. Poet Energy. *Company website: cellulosic ethanol*. 2009 [cited 2009 May]; Available from: www.poetenergy.com/learn/cellulosic.asp.
34. Abengoa Bioenergy. *Biomass enzymatic hydrolysis*. 2009 [cited 2009 May]; Company webpage]. Available from: www.abengoabioenergy.com.
35. Curran, H., *TMO Renewables*, in *World Biofuels Markets*. 2009: Brussels.
36. Baghaie-yazdi, N., *Biocaldol*, in *London Technology Network: Advanced-generation biofuels*. 2009: Royal Geographical Society, London.
37. Sutcliff, S., *Butanol - driving down the cost of biofuels*, in *F.O. Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
38. Baruch, T., *CMEA Ventures: presentation to the Biofuels Investment Forum*, in *World Biofuels Markets*. 2009: Brussels.
39. Shell. *Royal Dutch Shell*. 2009 [cited 2009 March]; Company website]. Available from: www.shell.com.
40. Mace, O., *BP Biofuel's strategy*, in *Marcus Evans - Biofuels Forum: evaluating and implementing future business opportunities*. 2008: London.
41. BP. *British Petroleum* 2009 [cited 2009 March]; Company website]. Available from: www.BP.com.
42. Morgen, C., *Inbicon: The result of DONG Energy's R&D on bioethanol*, in *Marcus Evans Biofuels Forum*. 2008: London.
43. Langvad, N.B., *Biogasol*, in *F.O. Lichts : developing and commercialising next generation biofuels*. 2009: Munich.
44. Cortright, R., *The BioForming® process: production of conventional liquid fuels from sugar*, in *F.O. Lichts: developing and commercialising next generation biofuels* 2009: Munich.
45. Riva, C., *The Verenium Corporation*, in *World Biofuels Markets*. 2009, : Brussels.
46. Peara, T., *Alternative Energy Finance: Securing finance for biofuels - where is the money coming from?*, in *World Biofuels Markets*. 2009: Brussels.
47. Morgen, C., *Dong Energy: Commercialising ethanol production from lignocellulosic biomass - making cellulosic ethanol work*, in *F.O, Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
48. Blondy, J., *Total: Biofuels, a conflict of generations?*, in *F.O.Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
49. Plaza, J., *Imperium Renewables*, in *F.O. Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
50. New, P., *BP Biofuels*, in *World Biofuels Markets*. 2009: Brussels.
51. de Bont, J., *Royal Nedalco*, in *F.O.Lichts: developing and commercialising next generation biofuels*. 2009: Munich.
52. Gilmore, R., *GIC Trading*, in *World Biofuel Markets*. 2009: Brussels.
53. Roberts, D., *CIBC World Markets: financing the next generation*, in *World Biofuels Markets*. 2009: Brussels.
54. Ouimet, G., *Sustainable Development Technology Canada: Examining the global biofuels market - where do biofuels investments lie?*, in *World Biofuels Markets*. 2009: Brussels.
55. Jerome Peters, *TD Bank N.A.: A look to the future*, in *World Biofuels Markets*. 2009: Brussels.
56. Haque, K., *Macquarie Bank International Ltd: Economic factors driving biofuels*, in *World Biofuels Markets*. 2009: Brussels.
57. Hasler, P., *Emerald Technology Ventures: VC and PE investment strategies in next generation biofuels*, in *World Biofuels Markets* 2009: Brussels.
58. Stark, M., *Accenture: Presentation to the Biofuels Investment Forum*, in *World Biofuels Markets*. 2009: Brussels.