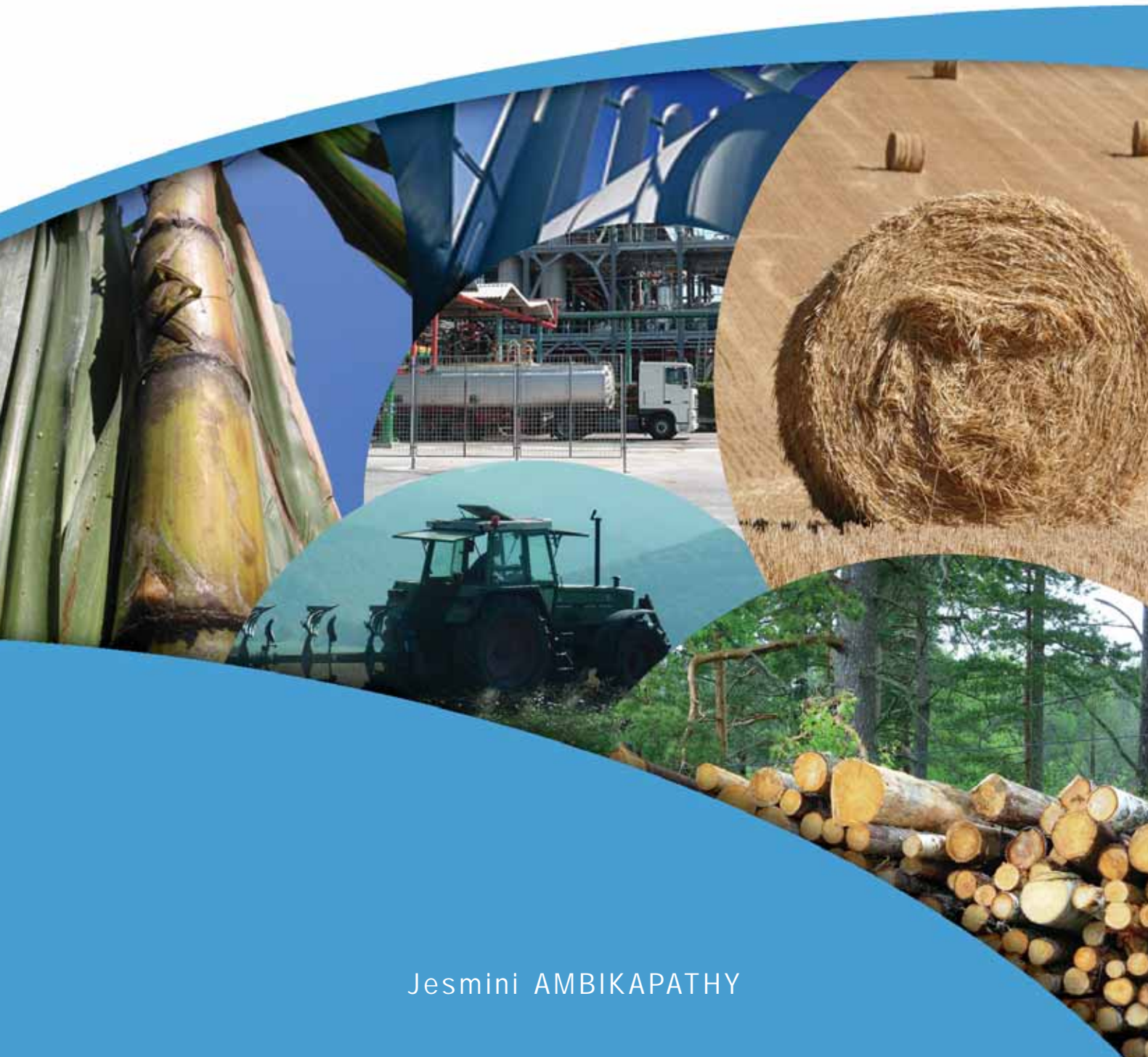


Status and Comparative Study:

Cellulosic Bioethanol production
in the US, EU and China



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Jesmini Ambikapathy

EuropaBio, the European Association for Bioindustries, represents more than 100 corporate and associate members operating worldwide, and 24 national biotechnology associations. Through our associations EuropaBio is also the voice of 1800 small and medium-sized enterprises involved in research, development, testing, manufacturing and commercialization of biotechnology applications. Our corporate members are involved in a wide range of activities: human and animal health care, diagnostics, bio-informatics, chemicals, biofuels, crop protection, agriculture, food and environmental products and services. EuropaBio's main mission is to promote an innovative and dynamic biotechnology based industry in Europe.

Europabio's Biofuels Task Force represents the biotechnology based biofuels and related companies at European level. Its mission is to advocate coherently favorable policies, strategies, regulations and their implementation for research, finance, and market access of Biofuels as one of the pillars of the competitive and sustainable European Knowledge Based Bio-Economy, increasing the value of plants and renewable materials of agricultural origin.

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Executive Summary

This paper has focused on the second generation, sugar platform technology for the production of ethanol from cellulose ('the Technology'), in three regions: China, the European Union ('EU') and the United States of America ('US'). Each region has approached the development of the Technology differently; engaging different groups, by different methods and at different stages. Despite these differences, each region is broadly equal when it comes to the state of the Technology, although it seems that the EU has a marginal lead. The focus in the EU seems to be refining the key technology steps (eg scaleup of fermentation technology and achieving cost reductions for cellulases), rather than developing them, as is the case in the US and China.

The drivers of investment in the EU and the US are essentially political. In contrast, China has immediate economic, social and environmental concerns that need to be addressed. In all three regions the primary investor in the Technology is government. The US government has engaged industry from the earliest stages of development. The EU and China are generally engaging industry at the pilot stage and pre-pilot development has primarily been the domain of government research facilities and academic institutions.

The US has a long history of investment in the Technology and now has a co-ordinated effort directed towards commercialising the Technology, with clear steps identified and articulated. The EU and China do not have the same history of investment or co-ordination, nor have they articulated the steps required to commercialise the Technology in the region. However, the EU is benefiting from the investment (both long and short term) of individual member states and is now providing funds to draw together relevant players in large EU-wide collaborative projects.

All regions believe that the development of the Technology will not be a barrier to the exploitation of the Technology. The most significant barrier to commercialisation in each region is the cost of capital of establishing the first commercial plant. The EU seems to have had the most success to date in overcoming this barrier, it is the first region to have begun construction of a commercial plant. Matched funding is being provided by the EC or governments of individual member states. The US government's proposal of providing loan guarantees has not yet been accepted by industry. China is currently implementing a new infrastructure for the development of renewable energy technology and clearly has the capacity to provide attractive incentives to overcome cost of capital issues.

It is likely that the first commercial demonstration of the Technology will be in the EU as the EU is currently providing the most attractive measures to overcome the main barrier to commercialisation. However, once the Technology is commercially demonstrated, it is predicted that it will rapidly be exported for exploitation in the US and China as:

- these regions will provide large markets with the potential for significant growth;
- very generous incentives exist for the creation of demand for ethanol in these regions;
- in the US, specific measures are being introduced to encourage both the supply and demand of ethanol produced from cellulosic material; and
- in China, there is the capacity and it seems also the intention, to do the same.

1. Introduction

1.1 Background

The use of ethanol in transport is not new. At various times during the 20th century it has been considered as a serious alternative to gasoline. When the first combustion engines emerged at the turn of the 19th century, the question of whether gasoline or alcohol was the better fuel provoked spirited debate.¹ The engine of Henry Ford's Model T could be modified to run on ethanol or gasoline.² During the oil embargos of the 1970s a number of countries began investing in programs to promote its use (eg Brazil, US and Sweden). Largely due to the wide availability and cheap cost of crude oil, ethanol has not taken off as a transport fuel of choice. However, in the last year, ethanol production, and in particular the production of ethanol from cellulosic material, has become a priority item on a number of national agendas.

1.2 Ethanol uses in transport

Ethanol has several uses in transport. It can be:

- blended with gasoline as an octane enhancer (10-15%);
- used as a gasoline substitute in a modified internal combustion engine;
- used as a blend in flexi-fuel vehicles (up to 85%);
- mixed with diesel using a stabilising additive (e-diesel); and
- used as fuel for diesel buses with an ignition improver.³

Ethanol has a lower energy content than gasoline (70%).

1.3 Ethanol production

Ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or materials that can be converted into sugar such as starch and cellulose. In the US, ethanol is principally produced from starch crops (corn); in the EU from starch (barley and wheat) and sugar (beet) crops; and in China from starch (corn and wheat) and to a lesser degree sugar (sugar cane) crops.⁴

Ethanol is generally produced from the fermentation of sugars. First generation processes typically rely on yeasts that convert six-carbon sugars (mainly glucose) to ethanol (and carbon dioxide). Starch is easily converted to sugar by acid or enzyme hydrolysis. The organisms and enzymes required for starch conversion of starch and glucose fermentation on a commercial scale are readily available. The conversion of cellulose to sugar is more complicated due to the presence of lignin and because cellulose is usually converted into both five- and six-carbon sugars (pentose and hexose, respectively) which require more sophisticated organisms for fermentation. There is virtually no commercial production of ethanol from cellulose, however, there is substantial research in the area and it is considered to be the next generation of technology for the production of ethanol ('second generation technology').⁵

1.4 Drivers for the production of ethanol

In the last 20-30 years, the ethanol market has primarily been created by generous government incentives on both the supply and demand side and been driven by various combinations of the following factors:

- **Energy security:** the 1970s oil embargos and the rising price of oil have motivated a number of governments to seek sources of energy produced from domestic resources.⁶
- **Energy supply:** to keep pace with rapid economic development and increased vehicle ownership.
- **Renewable energy sources:** global oil production is expected to peak after 2020 or 2030, use of alternative renewable energy sources is seen to be a means to delay peak oil production.⁷
- **Agriculture:** ethanol production from agricultural crops has created new markets for domestic agriculture producers.
- **Crude oil prices:** the price of crude oil has risen to its highest real level in over 20 years, averaging more than US\$50 per barrel in 2005.⁸

- **Environment:** large scale use of alternative fuels from non-fossil energy sources, such as ethanol, is one of the main strategies for the reduction of green house gas emissions.⁹ A reduction of up to 30% of CO₂ emissions can be achieved with a 10% blend of ethanol and gasoline.¹⁰

Interest in the production of ethanol from cellulosic material is being driven by the following additional factors:

- **Abundant raw material (biomass):** among the three raw materials (sugar, starch and cellulose), cellulose represents the most abundant global source of biomass and has to date been largely unutilised.¹¹ The global potential for biomass could be sufficient for twothirds of current global demand for transport energy without influence on any other usage.¹²
- **Lower cost of raw material:** cellulosic materials include low or no value wood, cultivation and waste products that are readily available and often discarded.
- **CO₂ emissions:** the production of ethanol from cellulose has the potential to have a lower carbon cost than production from starch or sugar.¹³
- **Greater capacity to improve technology:** ethanol production from starch and sugar has limited potential for substantial improvements in volume and cost.¹⁴
- **No competition with food production:** the use of starch and sugar crops in the production of ethanol competes with the food uses of these crops.

1.5 Aims

This paper will focus on the second generation, sugar platform technology for the production of ethanol from cellulose (**'the Technology'**) in three regions: China, the European Union (**'EU'**) and the United States of America (**'US'**). There is a large volume of disparate information available in this area from a wide variety of sources. The aim of this paper is to synthesise this information and provide a coherent, comparative overview of the development and exploitation of the Technology in these regions. In each of these regions, this paper will aim to identify the:

- current state of the Technology;
- current players and drivers of investment in the Technology and its exploitation; and
- main barriers to the exploitation of the Technology.

This paper will conclude with a comparative evaluation of the measures in each of the regions and predictions as to the future development of the Technology.

This paper will not look at the thermochemical platform for the production of ethanol from cellulose.

1.6 Methodology

Material was obtained primarily:

- from the websites of:
 - relevant government organisations (reports, fact sheets, briefing documents, presentations, position papers, policy documents)
 - research organisations (research interests, papers, presentations)
 - industry players (press releases, areas of research, collaborations, vision statements, presentations)
 - non-government organisations, such as industry bodies and interest groups (statistics, policy documents, industry reports, presentations); and
- for academic publications, by searching document databases using 'Google Scholar' (eg elsevier, science direct, pubmed).

The last year has seen rapid movement and increased activity in this area and many publications are out of date and do not represent the current state of affairs. To address this deficiency, interviews were also sought with representatives from all sectors engaged in the development and exploitation of the Technology in the three regions. Appendix A includes a **confidential** list of all the organisations contacted. Appendix B contains a **confidential** list of the people interviewed.

2. THE TECHNOLOGY

2.1 Feedstocks

There are four main sources of cellulose resources ('**feedstocks**');

- **wood residues** from the wood industry, including paper mills, saw mills and furniture manufacturing;
- **agricultural residues** including straw, corn stover, bagasse and husks;
- **dedicated energy crops** including woody and herbaceous crops, primarily tall grasses; and
- **municipal solid waste**, including paper and other cellulosic materials.

2.2 Summary of the process technology

The conversion of cellulose to ethanol requires:

- **pre-treatment** (or delignification) to liberate cellulose and hemicellulose from their complex with lignin;
- **hydrolysis** of the carbohydrate polymers to produce free sugars; and
- **fermentation** of free sugars (hexose and pentose) to produce ethanol.¹⁵

2.2.1 Pre-treatment

There are a number of pre-treatment methods available which broadly fit into two categories: physical (eg high pressure steam explosion or liquid hot water treatment) and chemical (eg dilute acid, lime or ammonia treatment) pre-treatment¹⁶. Pretreatment has been viewed as one of the most expensive processing steps in the production of cellulose to ethanol. However, pretreatment also has great potential for improvement of efficiency and lowering of cost through research and development.¹⁷

2.2.2 Hydrolysis

Cellulose and hemicellulose can be hydrolytically broken down into free sugars either enzymatically (cellulase and hemicellulase) or chemically (sulphuric or other acids).¹⁸ Hydrolysis of cellulose and hemicellulose produces both pentose (eg xylose and arabinose) and hexose (eg glucose, galactose and mannose) sugars. Acid hydrolysis is expensive and the process appears to have limited potential to be improved. Considerable research is being invested in improving the efficiency and reducing the cost of enzymatic hydrolysis.¹⁹

2.2.3 Fermentation

Hexose is readily fermented to ethanol by many naturally occurring organisms but pentose is fermented to ethanol by only a few native strains and usually at relatively low yields²⁰. Xylose and arabinose generally comprise a significant portion of hardwoods, agricultural residues and grasses, and must be utilized to make the economics of biomass processing feasible²¹. Genetic modification of bacteria and transformation of yeast with bacterial genes has produced strains capable of co-fermenting both pentose and hexose to ethanol and other value-added products at high yields.²²

2.2.4 Biorefineries

In the long term, it is expected that ethanol will be only one of a variety of value-added products that may be extracted from cellulosic biomass ('biorefinery').²³ In addition to ethanol, forty chemicals and feedstocks have been identified as potential products from cellulosic biomass.²⁴

2.3 Summary of the current process economics

The current estimate of net cost of ethanol produced from cellulose (verge-grass) is €0.75– 0.92 per litre, as compared with €0.34 per litre for ethanol produced from grain (corn).²⁵ Table 1 breaks down the estimated costs from three different cellulose feedstocks (verge-grass, willow-grass and wheat milling residues) when the lignin-rich fraction and other organic wastes from the process are used to produce heat and power. The capital (31-36%) and cellulase (36-48%) costs are the major cost drivers.²⁶ The cost of transportation of feedstock to an ethanol plant is also a key cost parameter. For example, IOGEN Corporation has determined that a plant needs to be located no more than 100 miles from the feedstock.

The establishment of biorefineries is considered by some to be the key to the economic viability of the Technology.²⁷ Revenue generated from the production and sale of high-value co-products of the ethanol production process can achieve significant improvements in process economics. One industry expert has suggested that if value-added products can be produced from lignin (eg textiles, packaging, vehicle manufacture), the Technology will have the potential to generate income “above and beyond” first generation ethanol processes.²⁸

Table 1: Summary of economic evaluation for a 156 kton/year bio-ethanol plant.

	Verge grass	Willow tops	Wheat residue
Feedstock (€/ton d.w.)	20	70	80
Total investment (M€)	313	285	235
O&M costs			
- Feedstock (M€/year)	13	39	38
- Cellulase (M€/year)	102	97	59
- Others ¹⁾ (M€/year)	19	14	11
- Total (M€/year)	134	149	108
Ethanol production cost			
- Feedstock (€/l)	0.06	0.19	0.19
- Cellulase (€/l)	0.51	0.48	0.30
- Other O&M (€/l)	0.09	0.07	0.06
- Capital (€/l)	0.37	0.34	0.28
- Gross ethanol price (€/l)	1.04	1.08	0.82
- Electricity ³⁾ (€/l)	-0.11	-0.10	-0.07
- Net ethanol cost (€/l)	0.92	0.99	0.75

Reith, J.H., den Uil, H., van Veen, H., de Laat, W.T.A.M., Niessen, J.J., de Jong, E., Elberson, H.W., Weusthuis, R., van Dijken, J.P., and Raamsdonk, L. (2002), “Co-production of bio-ethanol, electricity and heat from biomass wastes”, contribution to the 12th European Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection, June 17-21, 2002, Amsterdam, Netherlands.

2.4 Commercial, Demonstration and Pilot Plants

Table 2 sets out the current pilot, demonstration and commercial plants, in each of the regions. For completeness the IOGEN Corporation demonstration plant has also been included.

Table 2: Current Pilot, Demonstration and Commercial Plants in North America, the European Union and China

Name	Type	Location	Owner	Year est.	Partners	Feedstock	Funding (EUR)	Process	Co-products	Status
ETEK Pilot Plant (NILE Project)	Pilot	Ömsköldsvik, Sweden	Etek Etanolteknik AB	2004	Etek Etanolteknik AB 3 regional energy companies University of Lund	Spruce saw dust	Total : 22M FP6: 7.7M	Enzymatic or dilute acid hydrolysis of hemicellulose and cellulose followed by fermentation and distillation.	Energy from lignin burnt in a boiler	Producing ethanol (400-500 litres per day from 2 tonnes dry material) but not economically viable. Feasibility study for demonstration plant under way.
Babiliafente Bioethanol Project	Commercial	Salamanca, Spain	Abengoa Bioenergy	2005	SunOpta BioProcess Group, University of Lund Ciemat, Abengoa SA Biocarburantes de Castilla y León S.A., Ecoagricola S.A, Novozymes A/S, Repsol-YPF S.A.	Barley & wheat straw	Total : 11.8M FP6: 4.5M (Abengoa: major funder)	Pre-treatment at high temperatures with acid or aqueous solution followed by simultaneous saccharification and fermentation	Chemicals Animal feed	Under construction Annexed to barley ethanol plant
Shanghai Pilot Plant	Pilot	Shanghai, China		2004	1 local company 3 universities/ institutes (inc East China University of Science & Technology) Ministry of Science & Technology	Saw dust and rice straw	Total: 1.7M	Acid and enzyme hydrolysis		Demonstration plant planned
IOGEN Demonstration Plant	Demonstration	Ottawa, Canada	IOGEN Corporation	2004	Shell, Goldman Sachs PetroCanada, Volkswagen, Plant construction company	Straw	Shell Goldman Sachs PetroCanada Volkswagen Canadian Gov	Multi-stage enzyme hydrolysis, advanced microorganisms (Saccharomyces) and fermentation systems that convert both C6 and C5 sugars into ethanol	Semi-waste to be upgraded (eg dry millers grain) will also be targeted co-products.	Producing 75 gallons per tonne straw, 200K gallons per year
IBUS Plant	Pilot	Denmark	Elsam Energy	2002	Elsam A/S Sicco K/S Royal Veterinary and Agriculture University Riso National Laboratory TMO Biotech Ltd	Straw	Total: 13.5M FP6: 6.45M		Electricity	

3. UNITED STATES OF AMERICA

3.1 Background

In 2005, the US produced 16.6 billion litres of ethanol.²⁹ The US is the second largest ethanol producer after Brazil. There are currently 100 ethanol plants in the US with 8 to be expanded and 33 under construction. Ethanol plants began to emerge in the late 1970s as a result of federal energy policy and state agriculture policy; however, the majority of plants have been established in the last 5-10 years. Most of the ethanol plants are located in the Midwest states (the 'corn belt') and are predominantly owned by agriculture-processing companies and farmers (typically through special-purpose cooperatives). The remaining plants are owned by a mixture of food product producers and regional and international ethanol producers.³⁰

The majority of ethanol produced in the US is used as a gasoline blending agent (E10: 10% ethanol to 90% gasoline).³¹ As of 2003, it was estimated that more than 2 million flexi-fuel vehicles had been sold in the US. Flexi-fuel vehicles are offered by Daimler Chrysler, Ford and General Motors. E85 (85% ethanol to 15% gasoline) use is more established among heavy-duty vehicles and in private and government fleets which have been operating since the 1980s.³²

The US Department of Energy ('DoE') and Department of Agriculture ('DoA') have predicted that by the middle of the 21st century the US should be able to produce 1.3 billion dry tons of biomass feedstock per year, enough to displace at least 30 percent of its current gasoline consumption.³³

3.1.1 Potential cellulose to ethanol feedstocks

A number of cellulosic biomass sources are under consideration, however, to date most research attention has been directed to corn stover, a by-product of the existing corn to ethanol conversion process.³⁴

3.2 Major drivers – political, economic, environmental and social

3.2.1 National Security

Defence and foreign policy experts increasingly point to the US's "oil addiction" as a "national security emergency".³⁵ A disruption in the supply of oil, for example, due to an attack on a major pipeline, could "send prices soaring, increase business costs and trade deficits".³⁶

3.2.2 Supporting the continued growth of the ethanol industry

US ethanol consumption is expected to rise from 15 billion litres in 2006 to 30 billion litres by 2012.³⁷ To maintain the tremendous expansion of the ethanol sector, the most recent DoA Baseline Projections suggest that much of the additional corn needed will be diverted from exports, causing an increase in the price of corn. In addition, not all buyers of US corn will tolerate such a price rise (eg Central American and Caribbean region). High costs of grain feedstocks will continue dependency on subsidies.³⁸ Increasing corn production by devoting more land to the commodity would probably draw upon lands less suited to the production of corn.³⁹

3.2.3 MTBE substitute

Nineteen state governments have recently banned or restricted the use of methyl tertiary butyl ether (MTBE) as an ingredient in gasoline after the chemical was detected in ground and surface water at numerous sites in the US. Consequently, there is an increased demand for ethanol as many oil refineries replace MTBE with ethanol.⁴⁰

3.3 Government incentives

3.3.1 Research and Development

The DoE Biomass Program (through National Renewable Energy Laboratory ('NREL')) supports research and development of the Technology through 20-60% cost share (depending on risk) partnerships with

industry.⁴¹ The Energy Policy Act of 2005 authorises US\$2.9 billion over 10 years for research and demonstration of new bioenergy crops, biotechnology for biomass processing, and development of bio-based products, such as cornbased plastics and soy-based lubricants.

The DoE also supports the Genomes to Life program begun in 2000. This program continues 20 years of US government investment in fundamental research at universities and research institutes, focussing on bioprocesses for cellulosic ethanol production, with the aim of increasing production efficiencies and reducing cost.⁴²

The DoA funds a number of projects for the development of energy crops. These projects are driven by individual universities and to date have largely been uncoordinated.⁴³ The DoE has requested US\$10M in its 2006-07 budget to build regional partnerships to draw together feedstock expertise and technology.⁴⁴

The US Transportation Bill provides US\$42 million over the next four years for the Sun Grant Initiative (SGI), a nationwide effort to promote research, extension and educational programs on renewable, agricultural-based energy systems and bio-based products.⁴⁵

3.3.2 Commercialisation

The Energy Policy Act establishes a program of loan guarantees for the construction of up to four demonstration biorefineries capable of producing ethanol and other high-value products from biomass and provides US\$1 billion in grants and incentives for the first commercial production of cellulosic ethanol. These programmes are to be administered by the DoE. In addition, the Energy Policy Act creates DoA small-business grants of up to US\$100,000 for biobased product marketing and certification.

On an informal basis the DoE actively facilitates industry partnerships, to promote the efficient development of the Technology and to ensure relevant expertise are brought together.⁴⁶

3.3.3 Market creation

Public policy is largely responsible for the supply and demand side of ethanol in the US.⁴⁷ A significant number of State and Federal incentives, promoting the development of an ethanol market in the US, have been in place since the 1970s.⁴⁸ The most significant current incentives are outlined below:

- a tax exemption applies to all levels of ethanol blending to the end of 2010 at a rate of US\$0.135 per litre
- income tax deduction for alcohol-fuelled vehicles and an alternative-fuels production tax credit
- tax incentives for alcohol fuels, available to blenders/retailers beginning in January 2005 (US\$0.135 per litre of ethanol at 85% or greater, US\$0.05 per percentage point ethanol for blends)
- a "renewable fuels standard" ('RFS') setting targets of 15 billion litres in 2006 and 28.4 billion litres by 2012
- for the purpose of meeting the RFS, 1 litre of cellulosic biomass ethanol is treated as 2.5 litres of renewable fuel through to the end of 2012
- mandate that at least 946 million litres of renewable fuel be produced per year using cellulosic biomass, beginning in 2013
- expands federal bio-based product procurement regulations, to require all federal agencies, contractors, and the US Capitol complex to use bio-based products.

3.4 Government initiatives

The Biomass Program is a DoE initiative and has five core R&D priorities, the two most relevant being the "Biomass Feedstocks" which develops technologies to provide biomass feedstocks to biorefineries and the "Sugar Platform" which studies and optimizes the chemical and biological processes that break down biomass into raw sugar components (including sugar platform biorefineries).⁴⁹

The NREL has constructed a pilot facility to test bioprocessing technologies for the production of ethanol (or other fuels or chemicals) from cellulosic biomass. The pilot plant facilities are available to industry and academia to support R&D.⁵⁰

The DoE also coordinates the Clean Cities Program, a locally-based, government and industry partnership with the purpose of expanding the use of alternatives to gasoline and diesel fuel. Infrastructure development (eg pumps in the ground for distribution) is the central aspect of the program's activities.⁵¹

3.5 Industry activity

There are no pilot, demonstration or commercial plants for the Technology in the US. The NREL pilot facility is available to industry to test bench research which negates the need for industry to establish its own pilot plants. The NREL pilot facility reduces:

- the level of investment required by industry to commercialise technology; and
- industry risk by delaying the requirement for industry to make large capital investments until later stages in the development.

Monsanto, Du Pont and Dow have been investing in the development of energy crops in partnership with the DoA.⁵² Du Pont has also been partnering with Diversa Corporation and the NREL since 2003 to develop a corn stover/fibre pre-treatment scheme and microbial biocatalysts that integrate with enzymatic saccharification (Integrated Corn-based Bioproducts Refinery Project).⁵³

Novozymes and Genencor partnered with the NREL in 2000 to develop improved low-cost cellulases. The technology developed through this partnership is being contributed to a number of pilot and demonstration plants in the EU and possibly China. Genencor is continuing to invest in its cellulase technology in both R&D and application research and is in discussions regarding potential partnerships outside of the NREL and DoE.⁵⁴

Abengoa Bioenergy and Novozymes have been partnering with the NREL since before 2003 to develop biorefinery technology including the integration of lignocellulosic conversion into dry milling (corn) ethanol production. The Babilafuente Bioethanol Project will be utilising technology developed through this DoE partnership.⁵⁵

Since 1997, the NREL has also been working with the Corn Refiners Association and the National Corn growers Association to design biocatalysts to ferment the available sugars in corn fibre. This technology is in the process of being incorporated into existing commercial ethanol plants. Avencine has also partnered with the NREL in relation to the conversion of corn stover to ethanol.⁵⁶

NatureWorks (formerly Cargill Dow) recently downgraded a biorefinery collaboration with Genencor.⁵⁷ This decision has led some to doubt the feasibility of the Technology.⁵⁸

"Progressive oil companies" like Shell and BP are interested in the area.⁵⁹ Shell is "probably the largest blender of transport biofuels" and has also established 300-400 E85 filling stations in US corn belt.⁶⁰

In 2002, Shell invested US\$46 million in IOGEN. In May of this year, Goldman Sachs also invested in IOGEN, bringing "additional financial resources and critical management expertise".⁶¹ Several venture-stage financings have also occurred within the past six months.⁶²

Flexi-fuel vehicles are offered by Daimler Chrysler, Ford and General Motors ('GM'). The production of these vehicles creates a real rather than hypothetical market for ethanol as a transport fuel rather than just as a blending agent. As flexi-fuel vehicles can run on 0-85% ethanol to gasoline blends, they allow the ethanol market to grow and allow increasing levels of ethanol to be used in these vehicles as it becomes available on the market. The presence of flexi-fuel vehicles on the road also encourages the development of infrastructure for distribution.⁶³

GM is the most aggressive automotive supporter of ethanol and has entered into a number of collaborations with ethanol producers (including Abengoa Bioenergy) to install E85 pumps and promote the availability of E85 with consumers and car dealers and is an active partner in the Clean Cities

program.⁶⁴ Ford and VeraSun Energy are partnering to develop a “Midwest Ethanol Corridor” of approximately 100 additional E85 stations in Missouri and Illinois.⁶⁵ Some in the automotive industry are not convinced that ethanol is an optimal biofuel as it may not operate as well as gasoline in a broad range of conditions. However, “ethanol has a track record” which makes it an appealing alternative at least in the short term.⁶⁶

3.6 Attitudes on the state of the Technology

There is general agreement from industry participants that the Technology will become commercially viable in 5 – 7 years and become competitive with gasoline by 2012.⁶⁷ However, if the current government funding commitment does not continue, this date could be pushed back at least a decade.⁶⁸

3.7 Barriers to commercialisation

3.7.1 Competing technologies and uses of biomass

There will be competition for R&D funding and market share from other foreign oil-displacing alternatives in the long to medium term. For example, the DoE Energy Hydrogen Program has an accelerated timeline for resolving technical and economic barriers with the goal of a 2015 commercialisation decision on hydrogen-powered fuel cell vehicles and the infrastructure to fuel them.⁶⁹ However, national security concerns as well as agricultural concerns are “driving strong bipartisan support for increased ethanol usage.”⁷⁰

3.7.2 Ethanol imports

Brazil currently produces ethanol more cheaply than the US. The US imposes a US\$0.143 per litre import tariff on all ethanol imports protecting the domestic ethanol industry from competition with cheaper imports.

3.7.3 Economic barriers

Current feedstock costs are estimated to be US\$53 a dry ton. However, NREL models have estimated that the feedstock costs need to be closer to US\$30. The DoE “no longer has the capacity or funds to tackle this issue” and it is hoped that the DoA will prioritise this issue and work with farmers to resolve it.⁷¹

Given the technical, economic and environmental uncertainties of the Technology, the first movers with this technology will take on significant risk. The US government is currently proposing to share this risk by providing loan guarantees.⁷² There are currently no pilot, demonstration or commercial plants in the US, this may be in part due to resistance from potential first movers who may require some of their risk to be shared.⁷³ Loan guarantees do not remove any risk for first movers. If the ethanol plant fails, the government only steps in to provide recompense to the financiers, it does not remove any risk for the first mover.

3.7.4 Technical barriers

The major technical barrier in the US is the production of organisms for the fermentation of hexose and pentose. However, the DoE recently put out a “Request for Information” on the issue and there seems to be a willingness from industry to pursue the problem.⁷⁴

3.7.5 Infrastructure barriers

Closer integration of ethanol production with other agri-industrial activities is likely to displace some traditional marketing and distribution channels for corn. The services of some grain elevators may no longer be needed in some areas if local corn supplies are used in their entirety for ethanol production.⁷⁵

4. EUROPEAN UNION

4.1 Background

The EU currently meets 4% of its energy needs from biomass, however there is the capacity for far greater utilisation.⁷⁶ It has been estimated that domestic biomass has the potential to cover between 27 and 48% of EU transport fuels needs by 2030.⁷⁷ Significant cost reductions in the ethanol production process would be needed to transform the technical potential into economic potential. A cost reduction of 20-30% is considered plausible if second generation technology can be employed (beyond 2010).⁷⁸

The EU currently has at least 22 commercial ethanol plants in 10 member states with 14 to be constructed and in 2005 produced three billion litres of ethanol.⁷⁹ Most of these plants were established in the past 5-10 years by players from a number of different industries: potable alcohol producers, chemical companies, sugar and starch producers, farmer cooperatives (esp. in France), state owned or sponsored ethanol producers and a few international ethanol producers. Ethanol is principally produced from starch (barley and wheat) and sugar (beet) crops and all commercial plants currently rely on first generation conversion technology.⁸⁰

4.1.1 Potential cellulose to ethanol feedstocks

A number of biomass sources are being evaluated in the EU, including:

- agricultural waste, such as wheat straw
- forestry waste, such as logging residues and paper production residues
- energy crops grown specifically for fuel, including poplar, willow, verge grass and other fast-growing trees and grasses.⁸¹

4.2 Major drivers – political, economic, environmental and social

4.2.1 Energy Security

The EU transport sector is 98% dependent on fossil fuels. Crude oil feedstock is largely imported and extremely vulnerable to any market disturbance.⁸² The Technology provides the opportunity to produce transport fuels from readily available domestic resources and enables a diversification of sources of supply of transport fuel.⁸³

4.2.2 Creating new agriculture markets and stabilisation of rural regions

Agriculture is an important industry in many member states. Increased competition in traditional agriculture markets is a continuing challenge to the viability of the industry in Europe. The production of ethanol from cellulosic biomass creates new markets for European agricultural products in two ways:

- it creates a new market for “energy crops”; and
- provides for greater utilisation of products from existing agricultural crops (eg processing residues).⁸⁴

It has also been estimated that some 50 000 to 100 000 additional jobs could be directly created inside the EU, most of them in rural areas, from the production of biofuels in transport to meet the 2010 targets.⁸⁵

4.2.3 Greater capacity to meet Kyoto Protocol targets in the short term

The Kyoto Protocol states that the EU should decrease its greenhouse gas emissions to 8% below 1990 levels by 2010. Ethanol is a direct substitute for fossil fuels in transport and can readily be integrated into fuel supply systems.⁸⁶ In addition, although the EU vehicle market is biased towards diesel vehicles, Europe has a greater capacity to produce ethanol than biodiesel, using less land and with more room to reduce costs through economies of scale.⁸⁷ This will enable the EU (and member states) to meet its Kyoto Protocol obligations more quickly.

The Biofuels Directive⁸⁸ “reference value” of 2% biofuels in the transport sector by 2005 has not been met. If the current trend in biofuel production continues it seems unlikely that the 2010 “reference value”

of 5.75% will be reached.⁸⁹ Further efforts are needed in order to achieve the reference values and development of innovative technologies is seen to be the key.⁹⁰

4.2.4 Enable continued economic growth.

Most member states have seen an increased proportion of their GNP spent on fossil fuel imports.⁹¹ Access to alternative transport fuel, that can be produced domestically, is considered an important measure to enable continued industrial growth in the EU.

4.2.5 Increasing community demand for renewable inputs

There is an increasing demand by consumers in the EU for products generated from renewable sources. For example, the biggest market for ethanol in Europe at present is for conversion into derivatives such as ethyl tertiary butyl ether (**ETBE**).⁹² As such ETBE producers are interested in the feedstock and process by which the ethanol they purchase is produced⁹³.

4.3 Government incentives

4.3.1 R&D and Commercialisation

Under Framework Programme Five (**FP5**) and Framework Programme Six (**FP6**) the European Commission (**EC**) contributed ?93.2M to 20 large scale, multi-partner biofuel projects, of which €34.2M was provided to 6 projects relevant to the development and exploitation of the Technology (see Table 3).⁹⁴ These projects ranged from bench research, to the optimisation of pre-treatment, to the establishment of pilot plants. EC funding ranged from 38 – 61% of the total project value.

Outside of the large projects funded by the EC, funding of R&D and commercialisation seems to be a matter for each member state and practices vary widely from member state to member state. For example, in response to the oil embargos of the 1970s, the Swedish government began investing in the development of alternative fuels, in particular, the conversion of wood biomass, due to its abundance in Sweden.⁹⁵ As a result of committed ongoing government investment, largely in state or state sponsored organisations, Sweden is now one of the most advanced members states in the EU in bringing the Technology to the market.

The Dutch government began investing in large projects to bring relevant stakeholders together as a result of both the Biofuels Directive coming into force and a coincident breakthrough in the fermentation of hexose.⁹⁶ Government investment tends to be on the basis of matched funding by the government, industry and R&D facilities.⁹⁷

Countries with strong agricultural economies are also investing in industry-led feasibility studies for the establishment of cellulosic ethanol plants (eg Germany and France).⁹⁸

Table 3: Projects Funded by the European Commission in relation to cellulosic conversion to ethanol

Project Name	Acronym	Programme	Duration	EC Funding (€)	Total Project Cost (€)	Lead Organisation
New Improvement for Lignocellulosic Ethanol	NILE	FP 6	2005 – 2009	7,700,000	12,637,826	Institut Francais Petrole
Biomass for the market competitive and environmentally friendly Synthesis of bio-products together with the production of secondary energy carriers through the biorefinery approach	BIOSYNERGY	FP 6	4 years (start date to be negotiated)	7,000,000	15,132,000	Energy research Centre of the Netherlands
Project for the Production of 200 Million Litres of Bioethanol in Babilafuente (Salamanca) from Cereals and Lignocellulose	Babilafuente	FP 5 and FP6		4,500,000	11,830,357	Abengoa
Technological Improvement for Ethanol Production from Lignocellulose	TIME	FP5	2002 – 2006	2,619,105	4,342,411	VTT Biotechnology
Co-production of Biofuels	IBUS	FP 5	2002 – 2006	6,450,000	16,000,000	ELSAM A/S
Development of a Biotechnological High Yield Process for Ethanol Production, Based on a Continuous Fermentation Reactor.	FERMATEC	FP 5	2003 – 2005	480,740	961,537	TECNIA- Processos e Equipamentos Industriais e Ambientais Lda

4.3.2 Market creation

Under FP6, the EC is contributing €8M (45% of the total project value) to the Bioethanol for the sustainable Transport initiative (BEST).⁹⁹ The objective of BEST is to promote the introduction and market penetration of ethanol as a vehicle fuel, to establish an infrastructure for supplying ethanol and to promote the use of ethanol cars and flexi-fuel vehicles.¹⁰⁰

The EU has not introduced a mandate requiring minimum levels of ethanol or renewable fuel to be blended with gasoline or diesel. However, the Biofuels Directive sets "reference values" for member states. Not all member states have implemented the directive.¹⁰¹ Some member states have introduced mandates to meet the reference values in the Biofuels Directive. Fuel mandates are in force in France and Austria and will come into force in Slovenia in 2006 and in the Czech Republic and the Netherlands in 2007. The UK and Germany have recently stated that they intend to introduce them.¹⁰²

As part of the reforms to the Common Agricultural Policy in 2003, special aid (€45 per hectare) for energy crops was introduced with a maximum guaranteed area of 1.5 M hectares; once the 1.5M hectare ceiling is reached, the amount of aid provided will reduce. It will be determined this year how aid for energy crops will be implemented.

The Energy Taxation Directive¹⁰³ makes it possible for member states to grant tax reductions/exemptions in favour of biofuels under certain conditions (eg the energy produced from biomass must have beneficial effects as compared with fossil fuels and there is no overcompensation). Eight member states (France, Germany, Italy, Spain, Sweden, United Kingdom, Czech Republic and Poland) have introduced tax concessions pursuant to the Energy Tax Directive. These tax concessions range from a 20 to 100% reduction in fuel duty.¹⁰⁴

4.4 Government initiatives

The European Commission ('EC') is seeking to take an "ambitious and co-ordinated approach to promote the use of biomass and biofuels" in Europe¹⁰⁵ and includes the:

- Biomass Action Plan
- EU strategy for Biofuels
- establishment of an industry-led European Biofuels Technology Platform.

The Biofuels Technology Platform aims to provide and implement a common European vision and strategy for the production and use of biofuels (including development of the Technology). Major European biofuels stakeholders are represented, including the agricultural and forestry sectors, food industry, biofuels industry, oil companies and fuel distributors, car manufacturers and research institutes.¹⁰⁶

There are many different mechanisms within the EU through which the development and exploitation of the technology can be promoted.¹⁰⁷ A number of proposals are being considered, including:

- Providing favourable treatment to second generation biofuels to encourage their development and commercialisation through amendment of the Fuel Quality Directive¹⁰⁸, Biofuels Directive and Energy Taxation Directive.
- Creating a favourable market climate for biofuel investment through harmonisation of national agendas of member states and encouraging long term measures.
- Incentives for environmental performance of individual fuels to ensure that CO₂ efficiency of biofuels is acknowledged and rewarded.
- Ensuring bio-residues from forestry, agriculture and other sectors are not classified as waste but are considered as a potential feedstock for fuel.
- Stimulating demand for biofuels by the promotion of clean road transport vehicles in publicly and privately owned vehicle fleets .
- Encouraging the production of biofuel feedstocks to generate economic growth and employment in less developed regions of the EU through the Structure and Cohesions Funds.
- Campaigns to inform farmers and forest holders about the properties of energy crops, mobilising the unused potential of forest-based energy.¹⁰⁹

4.5 Industry Activity

Representatives from the agri-biotech sector were not prepared to provide information in relation to their interest in the Technology, this tends to indicate that there is activity in the pipeline.¹¹⁰

A number of consortiums are identified in Table 2 and Table 3. Novozymes is contributing its cellulase technology (developed in partnership with the US DoE) to the Babilafuente Bioethanol Project. Genencor is contributing its cellulase technology (also developed in partnership with the US DoA) to the establishment of the only non-EC funded pilot plant in the EU, a consortium sponsored by the French National Research Programme for Bioenergy (50% matched funding) and managed by ADEME. Consortium members include Tembec R&D Kraft, INSA Toulouse's Laboratory for Biotechnology and Bioprocessing, University of Bordeaux's Pine Institute. The project is valued at €1.5M.¹¹¹ The consortium will carry out a three year base line study of technical and economic results of a small pilot plant installed at a pulp mill with a view to establishing advanced biorefineries attached to paper pulp industry. Genencor and Novozymes are also providing a number of other projects access to their cellulase technology.¹¹² It has been suggested that more activity may be announced soon.¹¹³ In member states with advanced projects (eg Spain) a number of small to medium sized industrial biotech organisations are also providing cellulase technology.¹¹⁴

Abengoa Bioenergy is the lead partner in the Babilafuente Bioethanol Project and has produced most of its technology in-house (both in the US, in part, in partnership with the US DoE, and Spain). It has "very ambitious" plans to take its technology to new markets once it has been demonstrated.¹¹⁵ A number of regional ethanol producers are currently participating in EC funded projects. For example, SEKAB, Sweden (BEST project, Örnköldsvik Pilot Plant, NILE project) and Nedlaco, Netherlands (BEST project and Netherlands Lignocellulose Bioethanol Project).¹¹⁶

Shell is the most prominent oil company in this area participating in, among other things, a feasibility study for a cellulosic ethanol plant in Germany, the BEST project in Sweden and the Netherlands Lignocellulose Bioethanol Project.¹¹⁷ Total "is actively involved in evaluating and developing different technologies ... including second generation ethanol production".¹¹⁸ BP has indicated that they also have an interest in the Technology but were not able to provide any information in relation to their interest.¹¹⁹

The sugar industry was a key player in the commercialisation of first-generation technology in Europe. The industry seems to be a supporting observer of the Technology, its interest arising from both the influence of first generation ethanol production on the prices of sugar cane and sugar beat and the production of cellulosic ethanol as a co-product of the sugar refining process.¹²⁰

Three car manufacturers are producing flexi-fuel vehicles in the EU: Volvo (S40 and V50)¹²¹, GM (Saab 9-5)¹²² and Ford (Focus and Focus CMAX)¹²³. GM, through Saab Automobile AB, is also a participant in BEST in Madrid, Spain¹²⁴.

The development of the Technology is attracting the entry of new players. For example, the Virgin Group recently announced the establishment of Virgin Fuels with the intention of investing US\$400M in ethanol production, including development of the Technology.¹²⁵

4.6 Attitudes on the state of the Technology

There seems to be some consensus in the EU as to the state of the Technology. Commercial demonstration of the Technology is expected within 2-5 years and is likely first to be in the form of "hybrid" grain and cellulose plants.¹²⁶ Full commercial demonstration of the Technology (stand-alone), is expected within the next 10-15 years.¹²⁷ The integrated biorefinery concept is expected to be the future application of the Technology.

4.7 Barriers to commercialisation

4.7.1 Competing technologies and uses of biomass

At least in the short term, the Technology is considered to have the greatest capacity to facilitate rapid market penetration and to allow fulfilment of Kyoto Protocol Targets. However, an important aspect of EU policy is competition. To ensure the delivery of competitive, renewable and secure biofuels the EC considers it important not to be locked into one product or technology today, but to create an environment in which such products and technologies can evolve.¹²⁸

4.7.2 Ethanol imports

If the EU obtains its ethanol from imports rather than domestic production, the cost will be approximately 25% lower and the global greenhouse gas benefits will be greater. However, the EU will not have the advantage of developing a new domestic fuel source, creating greater security of supply, and there will be no rural development benefits.¹²⁹ The EC intends to adopt a “balanced approach” to the importing of ethanol, maintaining current trade arrangements but continuing to ensure that there is sufficient incentive for ethanol to be produced within the EU.¹³⁰

4.7.3 Economic barriers

Cost of capital is one of the major economic barriers to the establishment of commercial plants in the EU. In addition a number of member states do not consider the production of ethanol from biomass as a cost-effective means of reducing greenhouse gases (eg countries like Finland and Denmark use considerable amounts of biomass for the production of heat and power which is currently more cost effective).¹³¹

It seems that economic barriers can easily be overcome with the provision of funding and so far the EC seems willing to step in. For example, it is providing part of the funds required for commercial demonstration of the Technology as part of the Babilafuente Bioethanol Project and it funds all but one of the pilot plants in EU.

Ethanol is likely to remain more expensive than petroleum based motor fuels even at relatively high oil prices. The high cost of ethanol will be passed onto consumers (or governments).¹³² As the Technology's potential is not yet fully understood (for example its potential for cost reduction, energy efficiency and CO₂ efficiency) there is uncertainty in the market and it has traditionally been difficult to attract investment.¹³³ Government (EC and member states) intervention (subsidies, tax concessions, grants) will be needed in the short term to ensure sufficient incentive for consumers to use ethanol as a transport fuel alternative and to encourage relevant stakeholders to invest in the development of the Technology. There are currently a number of proposals being considered by the EC to allow favourable treatment of second-generation biofuels.

4.7.4 Technical barriers

The full development of the Technology is still perceived as a barrier, in particular:

- Cellulase cost reduction
- Fermentation scale up
- Economic pre-treatment
- Selection of feedstocks.¹³⁴

Although these barriers have been identified, only one commentator was “sceptical” that they would be overcome even within 10-15 years.¹³⁵ The fact that a number of projects have progressed to a pilot plant stage or beyond and that there is increasing interest from industry in the development of the Technology, tends to indicate that there is a belief that these technical barriers can and will be overcome.

If agricultural residues are to be utilised, there will be challenges in amassing this biomass for ethanol production. For example, about 35% of the annual growth of wood in EU forests is not used.¹³⁶ Most of the unused resources are in small private holdings, making their mobilisation difficult. In addition, in some countries there is limited biomass potential (eg Malta and Cyprus).¹³⁷ This lack of availability of adequate

amounts of biomass will add to feedstock costs, production costs and ultimately the cost of ethanol to the consumer.

4.75 Infrastructure barriers

When ethanol is blended with gasoline it can, to a large extent, be distributed through existing gasoline distribution networks. However, there is currently a very limited distribution infrastructure where ethanol is used as a transport fuel in its own right.¹³⁸ The BEST initiative is specifically set up to, among other things, address this type of infrastructure barrier.

5. CHINA

5.1 Background

China has been a fast mover in relation to the exploitation of first-generation technology. In 2002, the National Biomass Ethanol Pilot Plant was launched in four provinces and expanded to nine provinces in 2004.¹³⁹ By the end of 2004, demand for ethanol reached 1.0Mt and ethanol blended gasoline represented 80% of the vehicle gasoline market in the Heilongjiang, Jilin, Liaoning and Henan provinces.¹⁴⁰ In 2005, China produced 3.8 billion litres of ethanol.¹⁴¹

China's ethanol industry comprises over 200 production facilities in 11 provinces, capable of producing more than 10 million tonnes of ethanol each year. Almost half of China's ethanol production is presently derived from inland grains, with the rest from cassava and molasses.¹⁴² New plants are under construction with a capacity of 1.2Mt per year.¹⁴³

Traditional biomass energy utilisation plays an important role in China.¹⁴⁴ In 2003, China's total traditional biomass energy utilisation (eg direct burning on low-efficiency stoves) was approximately 14% of total energy consumption or 50% of total rural energy consumption¹⁴⁵. This indicates that there is potential for greater utilisation of biomass in China, such as the production of ethanol from cellulose.¹⁴⁶

5.1.1 Potential cellulose to ethanol feedstocks

China's principal cellulose resources are from agriculture and forest industry residues, animal manure from medium to large-scale livestock farms and municipal solid waste.¹⁴⁷ These cellulose resources are widely distributed and available in all regions of the country¹⁴⁸.

5.2 Major drivers – political, economic, environmental and social

5.2.1 Heavy dependence on imported oil

China is the second largest oil consumer in the world and has been a net importer of gasoline since 1993, importing more than 120 million tonnes of crude oil last year.¹⁴⁹ China is looking to its large biomass resources, to reduce dependency on imported oil.¹⁵⁰

5.2.2 Rural Development

Ethanol production is seen to be a means of generating income for farmers left behind by China's growing economy, promoting rural industrialization and the generation of employment.¹⁵¹

5.2.3 Increasing vehicle ownership

Private vehicle ownership has increased 6 fold in 10 years and further growth is expected.¹⁵² The growth of demand for ethanol may outweigh growth in production. Projections show that a large increase in production will be required to blend 10% ethanol into all Chinese cars by 2020.¹⁵³

5.2.4 Maintaining economic growth

China is in a period of rapid economic growth, its GDP is expected to quadruple by 2020.¹⁵⁴ As a consequence, the demand for energy has increased dramatically and there is "a huge sense of urgency" to find alternatives and ensure that economic growth is maintained.¹⁵⁵

5.2.5 Air pollution

Increased vehicle ownership has seen an increase in emissions adding to air pollution, particularly in major cities.¹⁵⁶ When ethanol is blended with gasoline it can reduce green house gas emissions.

Excess crop residues that do not readily decay are being burned off fields to avoid infestation problems. This is causing severe air pollution. There is now a ban on burning near airports, railroads and highways. However, it is thought that productive uses of crop residues are needed otherwise the ban will be difficult to enforce.¹⁵⁷

5.2.6 Food security and efficient land use

Food security is a long standing concern in China and China is keen to meet much of its needs with domestic production.¹⁵⁸ As farmland is limited, the top priority for land use is food crops.¹⁵⁹ All current ethanol feedstocks are sources of food and animal feed. It will be difficult to divert these feedstocks to ethanol without disrupting existing food markets and the Chinese government is reluctant to reduce the availability of food resources by introducing competition for land use and non-food uses of agricultural crops.¹⁶⁰

5.3 Government incentives

Total subsidies for ethanol in 2004 were 540 million RMB (€53.4M).¹⁶¹ Under the new renewable energy laws, it is anticipated that current regional incentive policies will be adopted more widely.¹⁶²

5.3.1 Research & Development

R&D grants for key biomass technologies are provided by the National Development Reform Commission and the Ministry of Science and Technology.¹⁶³

5.3.2 Commercialisation

Capital investment subsidies are normally provided by central government in the form of low interest loans.¹⁶⁴ Generous income tax concessions apply to the following types of enterprises during the first years of operation:

- acknowledged by the State as lying within new and high-technology industrial zones
- employing waste as a main raw material
- foreign-funded enterprises in middle and western areas of China
- foreign-funded enterprises in eastern areas of China that reinvest in central and western areas of China.¹⁶⁵

5.3.3 Market creation

In February 2004, five provinces (accounting for 16% of China's passenger vehicles) introduced a mandatory 10% blend of ethanol in gasoline.¹⁶⁶

A total VAT refund is available for ethanol production and consumption. If gasoline is blended with ethanol the VAT for gasoline is zero. The wholesale price of ethanol is calculated at 91.11% of the current No. 90 gasoline (which is most widely used among car drivers) factory price. Gasoline and ethanol blends have a retail price of the same grade of unblended gasoline. Subsidies are also provided for losses associated with the production, transportation and sale of ethanol.¹⁶⁷

5.4 Government initiatives

New renewable energy laws took effect in China on 1 January 2006 and confirm the importance of renewable energy sources in China's national energy strategy.¹⁶⁸ The laws are designed to encourage investment in the development of biomass technologies in China by creating certainty in the Chinese energy market.¹⁶⁹ Traditionally, China has had poor basic facilities and an investment shortage for the development of the energy industry.¹⁷⁰ The new laws are intended to provide long term, coordinated and coherent approach to energy policy and provide a sustainable financial source for biomass energy projects.

Research on ethanol feedstocks and conversion technologies has been undertaken since the 8th Five Year Plan for National Economic and Social Development (1991 – 1995).¹⁷¹ Pilot Technology, developed by East China University of Science and Technology, was funded under the 9th five-year plan (1995 – 2000).¹⁷² Under Programme 863 (the national hi-tech research and development program to stimulate the development of advanced technologies in a wide range of fields for the purpose of rendering China independent of financial obligations for foreign technologies), a biomass to liquid fuel technology project was funded at the Changsha Institute of Technology.¹⁷³

China is enhancing renewable energy cooperation with other countries and actively importing advanced technology, experts, experience and investment from abroad.¹⁷⁴ At the national level, China is investing in Brazil, with a view to importing considerable quantities of ethanol in the future and is working towards a committed trade relationship.¹⁷⁵ China is also collaborating with Spain, more generally, in relation to renewable energy¹⁷⁶. China is also acquiring land in other countries, for the production of ethanol feedstocks. For example, land in Laos is being assessed for cassava crops and ethanol production for China.¹⁷⁷

5.5 Industry activity

China has been conducting research into the conversion of cellulose to ethanol for over 20 years (Institute of Process Engineering, Chinese Academy of Science, Zhe Jiang University, Tsinghua University, Shandong University, Shanghai University, Jaopong University).¹⁷⁸ However it is only in the last five to six years that industry has become interested in the Technology. Chinese grain ethanol companies are now engaging with universities and research institutes to either collaborate in the development or to purchase the Technology.¹⁷⁹

Grain ethanol companies are investing in the Technology to expand ethanol production potential; depending only on grain feedstocks is not considered to be sustainable nor will it allow the industry to grow.¹⁸⁰ It is understood that Cofco Grain and Oil is currently collaborating with Novozymes.¹⁸¹ Novozymes is in the “advanced stages of the development” of the Technology and China is considered an important strategic market, its collaborations are, however, confidential.¹⁸² Henan Thian Guang Enterprise Growth Ltd is understood to be collaborating with Genencor to develop the Technology.¹⁸³

A collaboration between Jilin Light Industry Design and Risø, Denmark has been established for the optimisation of pre-treatment methods of substrate such as corn stover.¹⁸⁴

The Shanghai pilot plant was funded by the Ministry of Science and Technology under Programme 863. One local company and three universities/institutes (including East China University of Science and Technology) participated in the project (see Table 2 for details).¹⁸⁵

The city of Nanyang is participating in the BEST project.¹⁸⁶ The project partners include the City of Nanyang, Tsinghua University, Ford Europe, Centre for Energy Policy and Technology (ICEPT), Imperial College of Science, Technology and Medicine.¹⁸⁷

5.6 Attitudes on state of the Technology

There is considerable variation in opinion as to when cellulosic ethanol will enter the market in China. Some stakeholders believe that China is capable of developing cheap but reliable Technology in as little as a decade¹⁸⁸. One stakeholder has predicted that the Technology will become viable in “3-5 years when compared with first generation technology.”¹⁸⁹ However, there is general agreement that China has the potential to be the first mover. If China is committed to the production of cellulosic ethanol, it will “just do it and the cost can be absorbed by the government if it is uneconomic.”¹⁹⁰

5.7 Barriers to commercialisation

5.7.1 Competing technologies and uses of biomass

A study assessing the feasibility of a first generation cassava ethanol plant (annual capacity of 1 Mt) is currently being carried out in the Guangxi Province¹⁹¹. Cassava has a high starch content and is abundant in southern provinces. It costs less than corn and can be grown on marginal lands.¹⁹² Cassava alone could supply as much as 4 million tonnes of fuel ethanol. Cassava is capable of being grown on the 1 million hectares of barren land in China, which would add another 21 million tonnes of the crop. There is also scope to achieve another 7 million tonnes by raising yields.¹⁹³

In the 1980's, the Chinese government promoted household biogas technology and after 20 years the technology has developed from single energy utilisation to comprehensive waste treatment and biomass energy use.¹⁹⁴ As gasification technologies are well advanced in China, thermochemical conversion of biomass to ethanol (gasification) is likely to be an attractive technology. China's huge energy demand is also driving research into a number of other competing uses of cellulosic biomass, in particular, there is a strong interest in biomass electricity generation and the production of briquetting fuel from biomass.¹⁹⁵

5.7.2 Economic

Demonstration and commercial plants employing the Technology will have high upfront capital costs¹⁹⁶. Traditionally there has been a lack of funds to support large scale demonstration projects in China. In addition, the biomass energy market in China is not well developed.¹⁹⁷ As stated above, it is anticipated that the new energy laws will overcome these barriers by providing a steady and sustainable financial source for biomass energy projects and more certainty for investment.

5.7.3 Infrastructure

Development of a new industry for modern biomass energy services requires significant business infrastructure development to:

- design, build, operate and maintain systems;
- effectively manage the business operations; and
- create customer awareness and understanding of appropriate levels of technology and service.¹⁹⁸

Through the success of the 2002 National Ethanol Project, China has demonstrated that where there is a commitment from the government at the local and central levels, appropriate infrastructure barriers can be overcome.

5.7.4 Technical

The key technology barriers for China are cheap and efficient enzymatic hydrolysis and engineering organisms for the fermentation of both pentose and hexose.¹⁹⁹ China is piloting its own technology but it seems it is also open to commercialising foreign technology through collaboration or purchase. Given this combined approach it is likely that China will be able to overcome these technical barriers.

6. COMPARATIVE EVALUATION

6.1 Capacity to stimulate R&D

In the EU and the US, research and development has been successfully stimulated where national governments have committed funds to universities and research institutions. However, in the EU it does not appear that industry has been engaged or encouraged to engage in the early stages of development of the Technology, whereas the US government has actively encouraged and successfully engaged industry from the beginning. China has a long history of research in this area. However, the application of the Technology has not occurred until quite recently. This in part may be attributed to the lack of an established network of research institutions and enterprise for the dissemination of technological information in China.²⁰⁰ Under the planning economic mechanism, R&D and commercialisation are separate programmes. Researchers tend to carry out their work without consideration of the market problems.²⁰¹

6.2 Creating favourable conditions for commercialisation

The EC is currently providing a significant amount of money to fund pilot and demonstration plants in the EU and is actively exploring a number of reforms to create a sustainable market for cellulosic ethanol. With the exception of Spain, the EC and the governments of individual member states are the primary drivers of the commercialisation of the Technology. In Spain, Abengoa Bioenergy is driving the commercialisation of the Technology, using EC funds to subsidise Babilafuente Bioethanol Project and commercially demonstrate its own Technology.

Despite the lack of research and enterprise networking, China has demonstrated that it is capable of rapid and successful commercialisation of technology where there is a strong government commitment. China has already successfully piloted its own Technology in Shanghai. However, it seems that China is open to either the commercialisation of its own locally developed technology and/or foreign Technology. It has been noted that prevailing practices of technology transfer to China often do not sufficiently take into account of the local conditions under which the imported technology has to be operated and managed and training required.²⁰² This problem may be alleviated by the increasing trend for foreign organisations to establish a presence in China rather than simply selling their technology.

The US has recently introduced a number of measures specifically targeted at encouraging the establishment of the first commercial plant; the principal incentive seems to be loan guarantees. As discussed in section 3.7.3, this may not be a sufficient incentive. The willingness of the EU to provide funding rather than loan guarantees may have influenced Abengoa's decision to commercially demonstrate its Technology in Spain rather than the US and may also be the reason why IOGEN is assessing the feasibility of establishing a commercial plant in Germany, rather than in North America. It appears that the US government creates favourable commercialisation conditions with generous incentives but industry is expected to drive the development of the Technology and assume more risk than in the EU or China.

6.3 Engaging industry

The EU is successfully engaging industry in the development and deployment of this Technology (but not in relation to basic research), through matched funding of pilot and demonstration plants and infrastructure projects. The establishment of the industry-led Biofuels Technology Platform is intended to facilitate further engagement of industry.

Government or government sponsored organisations, were instrumental in the successful implementation of the 2002 Ethanol Project in China. It is likely that these organisations will also participate in the development of the Technology; driven by the perception that the grain ethanol industry is not sustainable.

It also seems that foreign industry players are pursuing opportunities through collaborations with local organisations in China, perhaps in order to access all available government incentives. It is considered likely that the government will offer similar incentives for the development and exploitation of the Technology as for first generation technology.²⁰³

The US has been the only region to be able to engage industry at all levels of the development of the Technology. However, this does not seem to have placed the US at a competitive advantage over the EU and China. Ironically, it has provided China and the EU with technology subsidised by the US government

6.4 Identification of clear research and development priorities

The US's research and development priorities are being set out in a Technology Roadmap.²⁰⁴ It is clear from the draft roadmap, that the US government understands the current status of the Technology and understands what needs to be achieved in order to make it commercially viable.

Individual EU member states, engaged in the development of the Technology, seem to have clearly defined research priorities (eg Sweden and the Netherlands). There is no clear statement of research and development priorities at the EU level. However, it appears that the broad research priorities for the EU are:

- improving the energy and carbon balance of technologies
- advanced technologies for the conversion of ethanol from a wider range of resources, including gasification of biomass
- dedicated energy crops to allow more efficient use of the whole crop
- cost reductions using advanced technology, through an economy-of-scale effect and a better integration into the fuel supply chain
- sustainability of the whole chain of biomass and biofuels production.²⁰⁵

The author was not able to uncover any articulated research and development priorities in China. It is clear that China is committed to meeting its increasing energy requirements from biomass; all renewable alternatives are being explored.

7. CONCLUSIONS

7.1 The Technology

Each region has approached the development of the Technology differently; engaging different groups, by different methods and at different stages. Despite these differences, each region is broadly equal when it comes to the state of the Technology, although it seems that the EU has a marginal lead. The focus in the EU seems to be refining the key technology steps (eg scale-up of fermentation technology and achieving cost reductions for cellulases), rather than developing them, as is the case in the US and China.

7.2 Drivers of investment

The drivers of investment in the EU and the US are essentially political. In contrast, China has immediate economic, social and environmental concerns that need to be addressed. In all three regions the primary investor in the Technology is the government. The US government has engaged industry from the earliest stages of development. The EU and China are generally engaging industry at the pilot stage and pre-pilot development has primarily been the domain of government research facilities and academic institutions.

The US has a long history of investment in the Technology and now has a co-ordinated effort directed towards commercialising the Technology, with clear steps identified and articulated. The EU and China do not have the same history of investment or co-ordination, nor have they articulated the steps required to commercialise the Technology in the region. However, the EU is benefiting from the investment (both long and short term) of individual member states and is now providing funds to draw together relevant players in large EU-wide collaborative projects.

7.3 Main barrier to exploitation

All regions believe that the development of the Technology will not be a barrier to the exploitation of the Technology. The most significant barrier to commercialisation in each region is the cost of capital of establishing the first commercial plant. The EU seems to have had the most success to date in overcoming this barrier, it is the first region to have begun construction of a commercial plant. Matched funding is being provided by the EC or government's of individual member states. The US government's proposal of providing loan guarantees has not yet been accepted by industry. China is currently implementing a new infrastructure for the development of renewable energy technology and clearly has the capacity to provide attractive incentives to overcome cost of capital issues.

7.4 Predictions for the future

It is likely that the first commercial demonstration of the Technology will be in the EU as the EU is currently providing the most attractive measures to overcome the main barrier to commercialisation. However, once the Technology is commercially demonstrated, it is predicted that it will rapidly be exported for exploitation in the US and China as:

- these regions will provide large markets with the potential for significant growth;
- very generous incentives exist for the for the creation of demand for ethanol in these regions;
- in the US, specific measures are being introduced to encourage both the supply and demand of ethanol produced from cellulosic material; and
- in China, there is the capacity and it seems also the intention, to do the same.

ANNEX

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