THE BIOLOGICAL UTILISATION OF BAGASSE: A SOUTH AFRICAN PERSPECTIVE

By

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Abstract

IN THE EARLY 1980s, the Sugar Milling Research Institute was part of a national collaborative program entitled 'The Biological Utilisation of Bagasse'. The aim was to develop and evaluate the expertise and technology required to provide biomass fermentation substrates (specifically from sugarcane bagasse) for ethanol, single cell protein and other industrial products. A number of processes were successfully developed on a pilot scale including acid hydrolysis, direct fermentation of the hydrolysate, production of single cell protein, hydrolysed fibre preparation for enzymatic hydrolysis using attritor milling and the production of very high activity cellulase. The processes were developed on a sufficiently large scale to allow for economic evaluation. Given the current interest in cellulosic fuels, the proposed use of sugarcane biomass feedstock for value-added addition and the possibility of sustaining ailing sugar industries, this paper highlights the processes that made the program successful, compares the historical and current economic and technical drives and comments on some current thinking in this field.

Introduction

In the early 1980s, the Sugar Milling Research Institute (SMRI) was part of a national collaborative research program entitled 'The Biological Utilisation of Bagasse'.

The aim of this program was to develop and evaluate the expertise and technology required to provide biomass fermentation substrates (specifically from sugarcane bagasse) for the production of ethanol, single cell protein and other industrial products.

This paper serves to highlight the diverse socio-, economic and technological drivers of that period that impacted on the program, explain the program and the outcomes achieved, reasons for its success and finally draws parallels to current drivers.

Economic drivers

During the 1970s, the world economy was stressed by two oil crises: in 1973, when Middle Eastern oil producing nations proclaimed an oil embargo in response to the U.S. decision to re-supply the Israeli military during the Yom Kippur war; and in 1979, in the wake of the Iranian Revolution.

Crude oil prices went as high as $100 / barrel (expressed in 2009 dollars) (Figure 1). The major producers of the time were the United States, Russia, Saudi Arabia and Iran.

The South African economy was, in addition to the international crude oil crises, being challenged by the start of selected economic sanctions.

Most of the country's crude oil was being sourced from Iran until the fall of the Shah in 1978.

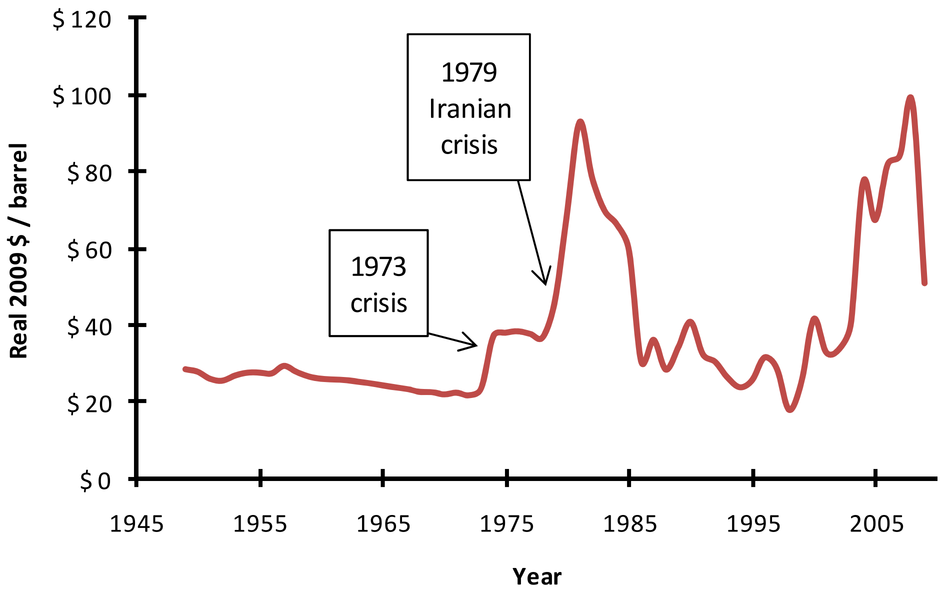

Fig.1—Average annual price of crude oil from 1949 to July 2009 expressed in 2009 dollars showing the spikes in 1973 and 1979 (Reproduced from EIA, US Department of Energy).

In 1955, a South African company called South African Synthetic Oil Limited (SASOL) started producing petrol, liquefied petroleum gas and other chemicals from coal using the Fischer-Tropsch process at Sasolburg (Collings, 2007).

Together with Total SA and the National Iranian Oil Company, a refinery (NATREF) was established in 1967 based on Iranian crude. Because of the 1973 oil crises, a second oil-from-coal complex was established (SASOL II), coming on-line in 1980. As a consequence of the Iranian Revolution and drying up of supplies from that country, a third SASOL complex was built adjacent to the SASOL II complex, coming on stream in the mid 1980s.

The three plants supplied approximately half of the country's liquid fuel requirements at the time. (This has declined over time as Sasol currently supplies approximately 36% of the country's fuel requirements (Anon., 2009a)).

Technological drivers

The 1970s witnessed an upsurge in technological advances that aided scientists. Examples include the adoption of liquid chromatography as a routine analytical technique due to advances in instruments and column packing material synthesis. These advances had a direct effect on the biological sciences with advances in molecular biology, bacteriology and genetics laying the foundations for the modern forms of these disciplines.

In 1973, Stanley Cohen and Herbert Boyer pioneered the techniques to create recombinant DNA (Anon, 2009b). This technology became the beginning of the biotechnology industry. Genetech was founded in 1976 with the aim to produce materials from the emerging technology. This set the stage for the investigation and use of biotechnology in the lignocellulosic field.

The program and its outcomes

During the 1970s, the Council for Scientific and Industrial Research (CSIR) funded stand-alone research at a number of different centres into the utilisation of lignocelluloses. In 1979, this research was consolidated into a goal-orientated, cooperative program to focus the effort on a single lignocellulosic material, to produce a single product and a single conversion process. The goal of the program was the development of a technically and commercially viable process to convert bagasse to ethanol (Paterson-Jones, 1989). Liquid fuel production was perceived as important at the time due to the drivers already mentioned.

Although several lignocellulosic resources were potentially available, bagasse was chosen because it was already being collected at a central location (the mill), it could be produced in excess of the mill's energy requirements and the mill could provide an established industrial infrastructure for a bagasse processing plant. Ethanol was chosen as the preferred end product because it had potential for use as both a liquid fuel and as a chemical feedstock. An enzymatic saccharification process for cellulosic hydrolysis cellulose was chosen because it held the promise of providing a high yield under mild conditions. It was also viewed that the enzyme process held the potential for improvement through research. The sponsors accepted that the program was a high risk venture but that it held potential benefits to South Africa. These included the development of a process which could be applied to other lignocellulosic wastes (with minor modifications) and produce a range of products including ethanol.

Eleven institutions throughout South Africa collaborated in the program. A total of fourteen research groups with a range of expertise in enzymology, microbiology, genetics and engineering were involved over the nine year period (Anon, 1989). The program was managed with a coordinator at both the scientific and administrative level and made extensive use of a steering committee. SMRI played a pivotal role as a contact point between the researchers in the program and the sugar industry. The Institute also hosted and was responsible for running the process development unit that ran for more than two years. The results from the development unit were used for subsequent economic modelling.

The program achieved successful outcomes in both the technical and human capital development arenas. Technically these included:

- The development of an acid-based extraction and hydrolysis of hemicellulose to xylose and other monomeric sugars using dilute acid.
- Direct fermentation to alcohol of the sugars in the hemicellulose hydrolysate.
- Production of single cell protein from the hemicellulose hydrolysate.
- Treatment of acid-extracted bagasse by attritor milling.
- Simultaneous enzymatic hydrolysis of the cellulose in acid-extracted, attritor milled bagasse and its fermentation to ethanol.
- Production of very high activity cellulase enzyme (57 IU/mL).

Human capital development within the program was evidenced by the awarding of 13 MScs, 5 PhDs, 47 papers in international peer reviewed journals, 33 conference papers and local expertise developed in fermentation research and technology and associated fields.

During the course of the program (1979 to 1987), a number of significant changes occurred within the drivers which had been present at the beginning of the program. The most significant globally was the decline in crude oil prices back to levels approaching the early 1970s (Figure 1).

The second significant change within the South African context was the coming on-line of the SASOL II and III plants (Collings, 2007). A by-product of the synthesis processes being used at that time was ethanol, which directly affected the potential development of a fuel alcohol industry. Throughout the duration of the program, the economic potential of not only ethanol but other products was investigated as the economic background changed. Potential products investigated included acetone, n-butanol, acetic acid, butane-2,3-diol, xylose, furfural, butadiene, sugar alcohols (mannitol, xylitol, etc), organic acids (citric, tartaric, lactic, etc) and amino acids.

Based on the processes developed and optimised using the process development plant, an economic evaluation showed that (Purchase, 1989):

- the production of ethanol from enzymic hydrolysed bagasse was not economically promising due to the high cost of enzyme;
- the production of single cell protein from hemicellulose hydrolysate was possible;
- the production of ethanol from hemicellulose hydrolysate was marginal.

Parallels to the present and future potential

On an international scale, some of the current economic drivers have parallels to those that were present in the late 1970s in South Africa and have to be considered when reviewing participation in renewable cellulosic feedstock research and developing related economic models. These include the fluctuating crude oil prices (such as the highs of 2008 which have subsequently declined in a similar fashion to the early 1980s (Figure 1)), the increasing supply of internationally traded fuel alcohol (particularly from Brazil which supplies more than 50% of global alcohol), the cost of finance (Tuxen, 2009) and the next step in the evolution of analytical instrumentation.

The sensitivity and types of instruments currently available provide the researcher with the ability to understand reactions and interactions at a molecular level which again promises to build a platform to make rapid progress in the enzyme field. However, although much progress has been reportedly achieved in enzyme efficiencies and reducing costs of production, enzyme costs are still considered to be inhibiting factors to the adoption of the technology (Tuxen, 2009).

In addition, a number of new economic drivers that were not present in the 1980s now have to be considered when venturing into renewable biomass research. These include global warming, land use change policies (Anon, 2009c), government policies relating to carbon credits and carbon tax (Winkler and Marquard, 2009), the United States Renewable Fuel Standard Program (Anon, 2009d) and similar programs which may include subsidies (Askew, 2003; Tuxen, 2009). The inclusion of these drivers in economic models for renewable energy makes long-term forecasting more difficult than 25 years ago.

From a sugar industry perspective, the use of sugarcane as a biomass source has many advantages including the plant being one of the most efficient utilisers of the sun’s energy and collection of the biomass at central locations. These advantages often encourage a perception among researchers outside the industry to view bagasse as an almost limitless resource freely available for enzymic conversion to fuel alcohol. Sugar mills are generally not energy efficient but rather energy sufficient: the energy produced from bagasse matches the desired configuration and operation of the plant and any other ancillary factories.

Large quantities of the raw material are therefore not necessarily available. Purchase and Wienese (2004) reviewed co-generation using bagasse and fuel alcohol from molasses, sugar and biomass hydrolysis. The authors estimated that, in the South African context, about one third of all bagasse is available for cellulosic ethanol production. This would contribute less than 1% of the current annual fuel requirements of the country (Anon, 2009a). It was concluded that the use of bagasse for co-generation is a better option than ethanol from cellulosic hydrolysis.

Conclusion

The biological utilisation of bagasse program was successful in both its technological and socio-economic outputs even though it did not create a new industry. There are lessons that can be learnt for any consortium planning an integrated approach to research.

The success was founded in well defined, achievable goals and appointing one leader responsible for co-ordination and overseeing the whole project. The outputs of the research were continually tested against the economic drivers within the context of the overall program goals.

Although there are many parallels between the current divers and those present in the 1980s, additional policies now make biomass derived renewable energy economically attractive. However, the widespread adoption of cellulosic enzymatically derived biofuels from sugarcane bagasse still has many barriers to overcome when compared to adoption of co-generation.

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L'UTILISATION BIOLOGIQUE DE LA BAGASSE: UNE APPROCHE SUD AFRICAINE

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MOTS-CLÉS: Bagasse de Canne à Sucre, Recherche Collaborative, Éthanol Enzymatique, Motivation Économique.

Résumé

AU DÉBUT des années 1980, le *Sugar Milling Research Institute* faisait partie d'un programme de collaboration national intitulé " L'utilisation Biologique de la Bagasse". L'objectif était de développer et d'évaluer l'expertise et la technologie nécessaires pour fournir des substrats de fermentation de biomasse (plus précisément à partir de la bagasse de cannes à sucre) pour la production d'éthanol, la protéine unicellulaire et d'autres produits industriels. Un certain nombre de procédés ont été développés avec succès à l'échelle pilote, y compris l'hydrolyse en milieu acide, la fermentation directe de l'hydrolysat, la production de protéines unicellulaires, la préparation de la fibre par l'hydrolyse enzymatique à l'aide d'un défibreur et de la production de cellulase à très forte activité. Les procédés ont été développés sur une échelle suffisamment grande pour permettre une évaluation économique. Compte tenu de l'intérêt actuel pour des combustibles à base de cellulose, l'utilisation proposée de la biomasse de la canne à sucre pour des produits à forte valeur ajoutée et la possibilité de venir en aide à des industries sucrières en difficulté, cette communication met en exergue les procédés qui ont fait le succès du programme, fait la comparaison entre les aspects historiques et courants des motivations économiques et techniques et offre des commentaires sur la reflexion actuelle dans ce domaine.

LA UTILIZACIÓN BIOLÓGICA DEL BAGAZO: UNA PERSPECTIVA SURAFRICANA

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PALABRAS CLAVE: Bagazo, Investigaciones Colaborativas, Etanol Enzimático, Conductores Económicos.

Resumen

A INICIOS de los 1980s, el Sugar Milling Research Institute era parte de un programa nacional colaborativo denominado 'La utilización biológica del Bagazo'. El objetivo era desarrollar y evaluar el nivel de especialización y la tecnología requerida para proveer un sustrato fermentable basado en biomasa (específicamente a partir de bagazo de caña de azúcar) para etanol, proteína unicelular y otros productos industriales. Se desarrollaron exitosamente un grupo de procesos a escala piloto, incluyendo hidrólisis ácida, fermentación directa de los hidrolizados, producción de proteína unicelular, preparados de fibras hidrolizadas para la hidrólisis enzimática empleando molinos de atrición y la producción de una celulasa muy activa...los procesos se desarrollaron a una escala suficientemente grande que permitía su evaluación económica. En razón del actual interés en combustibles celulósicos, la propuesta de empleo de alimentos de la biomasa de la caña de azúcar para generar valor agregado y la posibilidad de una industria azucarera sostenible, este trabajo destaca los procesos que hicieron exitoso el programa, compara los promotores económicos históricos y actuales, así como los tecnológicos y comenta sobre algunas consideraciones actuales en este campo.