   

Employment-oriented Industry Studies

Innovation in Resource-Based Technology Clusters: Investigating the Lateral Migration Thesis

The development of a sugar-based plastic in Brazil

L. Velho & P. Velho

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Resource-Based Industries

Innovation in Resource-Based Technology Clusters

Investigating the Lateral Migration Thesis

The development of a sugar-based plastic in Brazil

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Abstract

Is there an inescapable dilemma between exploiting natural resources and becoming knowledge-intensive? This article presents a case study that provides evidence that natural resource-based activities can be knowledge industries. The case in question is the establishment of an industrial plant to manufacture biodegradable plastic from sugar in Brazil. This development is closely associated with the long term activity of sugar and alcohol production in Brazil, which is based on the natural endowments of soil, climate and geographical extension that favors sugar cane cultivation. This notwithstanding, the emergence of the bioplastic industry was only possible because of a specific government scheme to build research capacity and knowledge production in biotechnology which also stimulated cooperation between the public and the private sector. Therefore, the most important lesson from the case seems to be that there is a key role to be played by public policies, and more specifically by S&T policy, if natural resources rich countries want to upgrade their related technological activities.

Acronyms

BNDES	National Bank for the Economic and Social Development
COPERSUCAR	Cooperative of Sugar and Alcohol Producers of the State of São Paulo
CTC	Technology Center Copersucar
DEMa/UFSCar	Department of Materials of the Federal University of São Carlos
EMBRAPA	Brazilian Corporation for Agricultural Research
IAC	Agricultural Institute of Campinas
ICB/USP	Institute of Biomedical Sciences of the University of São Paulo
INPI	National Institute of Intellectual Property
IPT	Institute for Technological Research
PADCT	Science and Technology Reform Support Program
PDE	Research, Development and Engineering
PHB-HV	Polyhydroxybutyrate/valerate
PHBISA	PHB Industrial
PLANALSUCAR	National Program for the Breeding of Sugar Cane
Proalcool	National Programa of Ethanol
SBIO	Biotechnology sub-program
USDA	United States Department of Agriculture

1 Introduction

It is common sense these days to say that countries must become "knowledge economies" if they want to participate in any meaningful way in the global market. However, despite earlier predictions that Latin American countries would follow the Asian manufacturing successes, evidence shows that the former´s rich natural resource endowments are still determining what they export. This is the case even for the most industrialized Latin American countries, including Brazil. In such circumstances it is highly relevant to ask whether that continued specialization in natural resources will leave Latin America behind in the slower "old" economy.

This article attempts to address the above question by analyzing a case that shows that there is not an inescapable dilemma between exploiting natural resources and becoming knowledge-intensive. The case is an example that natural resource-based activities can indeed be knowledge industries. The argument is that for this to happen it is necessary an enabling environment in which public policy plays an essential role. Policy actions include macro-economic and industrial policies that affect directly or indirectly the exploitation of natural resources and the industries associated to it, but more specifically S&T policies. The latter are crucial to create human capital as well as the linkages between private firms, government research institutions and universities.

The case in question is the establishment of an industrial plant to manufacture biodegradable plastic from sugar in Brazil. This development is closely associated with the long term activity of sugar and alcohol production in Brazil, which is based on the natural endowments of soil, climate and geographical extension that favors sugar cane cultivation. This notwithstanding, the emergence of the bioplastic industry was only possible because of a specific government scheme to build research capacity and knowledge production in biotechnology which also stimulated cooperation between the public and the private sector.

In order to tell this story and develop the argument, it is necessary first to set the scene. Thus, the historic context which created the conditions and the motivations for the development of the biodegradable sugar-based plastic is presented in Section 2. This is followed by an account of the R&D project that originated the industry in question, highlighting the role of the various actors and the relations between them (Section 3). Section 4 then provides a description of the technological process for obtaining a sugar-based plastic that was developed by the R&D project, transferred, scaled up and adopted by the industry.

The last three sections focus on specific aspects of the development of the bioplastic. Section 5 provides data on the financial dimension of the project and Section 6 on the outputs generated in order to illustrate the impact of the project on research capacity building and knowledge production. A summary of the key features of the project is provided in Section 7. The concluding section that closes the article points out the main findings relevant for the argument.

2 The context and the motivation of the research project for the development of a biodegradable sugar-based plastic

Brazil is the world's largest producer and exporter of sugar. From its sugar cane, Brazil produces not only raw and refined sugar but also anhydrous and hydrous alcohol mainly used as a blend in domestically-consumed gasoline. During the last quarter of the past century the expansion in sugarcane production and processing in the country has been astonishing and was driven by different factors. Starting in the mid 70's, the ethanol program (PROALCOOL)[1] increased the production of that fuel 30 fold, a process that occurred in two phases. Firstly by expanding the crushing capacity of the already existing sugar mills with adjacent distilleries and secondly by building new autonomous plants, dedicated only to the production of ethanol.[2] Sugar cane producers were quick to respond to the demands created by PROALCOOL. Credit guarantees and low-fixed interest-rate subsidies were provided for the construction of distilleries as well as for purchasing land. Moreover, in 1979, the price of hydrous-alcohol-powered vehicles was set at 65 percent of the equivalent price for gasoline-powered vehicles and taxes for these vehicles were also set below those for gasoline-powered vehicles, thus stimulating alcohol production. Furthermore, gas stations were allowed to supply alcohol for alcohol-powered vehicles all weekend, whereas gas stations were closed for gasoline-powered vehicles on the weekend. Petrobras, the state oil company, controlled ethanol distribution. As a result, the production of ethanol alone jumped from 0.55 to 15.3 million of cubic meters between 1975 and 2004. Growth of sugar cane production followed suit increasing from 64 million ton/year in 1975 to 350 million ton/year in 2004.[3]

Brazil has now an installed capacity of sugar cane processing of 360 million tons per year, crushed in 320 mills concentrated in two distinctive production areas, comprising approximately 5 million hectares of land.[4] The Center-South region is characterized by highly productive soil and excellent growing conditions and is one of the lowest cost growing areas in the world, estimated at 5 to 5.5 USD cents per pound. This region concentrates 85% of the Brazilian production, which is harvested and processed from May to November. The North-Northeast region produces the remaining 15%, which is harvested and processed from December to July, and is characterized by generally low yields and high costs due to periodic drought and poor soil. Nowadays Brazil

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[1] Although the primary cause for the development of PROALCOOL was the sharp increase in petroleum prices in 1973 and the country's heavy dependency on imported crude oil, another impetus was the collapse of sugar prices on the world market in November 1974. With the creation of PROALCOOL, sugar was transformed into alcohol, strengthening the options for its use. Response to the stimulus of the program came primarily from the sugar producers, who undertook rapid construction of adjacent distilleries to use the surplus of sugar cane.
[2] Adjacent distilleries are those built alongside a sugar mill and use all the existing structure and facilities. They can process either residual molasses from the production of sugar or cane juice. The autonomous distilleries are those built exclusively to produce ethanol from sugar cane juice.
[3] Negrão 2005 (personal communication).
[4] Brazil has about 320 million hectares of land suitable for cultivation and only 53 million are under production. Sugarcane accounts only for about 5 million hectares or less than 10% of the total cultivated area. Sugarcane area is considerably less than that planted to other crops like corn, rice and soybeans, of course with different social functions.

diverts 55% of the sugarcane to ethanol production and the remaining 45% to sugar production.[5]

In parallel to the expansion of sugar cane production and its traditional processed products (sugar and alcohol)[6], PROALCOOL earmarked part of its loans taken from the World Bank, to R&D activities. The latter included research on alternative raw materials for alcohol production (such as starch from cassava) but concentrated on the strengthening of sugar cane breeding programs[7] and on the improvement of new sugar extraction and fermentation processes as well as in the introduction of computer-assisted equipment for all industrial processes and utilization of sugar cane processing by-products.[8]

The knowledge generated by such R&D activities as well as the learning accumulated by the sugar cane mills resulted in considerable increase not only in sugar cane productivity but also in sugar and alcohol yields, as illustrated in figure 1. Another significant impact was a drastic reduction of production costs, not only of ethanol but also of sugar cane and sugar. Today Brazil is the lowest cost producing country of both ethanol and sugar. For the latter, figure 2 presents relevant comparative information with other sugar producing countries.

[5] In great numbers we can say that 1 ha of land produces an average of 82 ton of sugar cane that processed can yield either 7,000 litres of ethanol or 12 t of sugar with some residual ethanol from the generated molasses.

[6] A vast array of other 'secondary' products to be obtained from the sugar cane industry residues are either being researched or already being produced namely: sweeteners (glucose and xylitol), single-cell proteins, lactic acid, microbial enzymes, etc…

[7] In the 70's and 80's, Brazil had three sugar cane breeding programmes – one maintained by the Agronomic Institute of Campinas (IAC) and funded by the state of São Paulo; one funded by the sugar and alcohol producers who were associates of the Copersucar; and one funded by the federal government and carried out by Planalsucar (the research branch of the national Institute of Sugar and Alcohol). The latter alone had a research budget which was close to 70% of the one for EMBRAPA (the Brazilian Corporation for Agricultural Research, a state-owned R&D nationwide network of agriculture research centres and experiment stations). The point here is that in the 80's EMBRAPA comprised 37 research programmes for many different crops and livestock, whereas Planalsucar was totally dedicated to research on sugar cane and its products.

[8] At the beginning of the PROALCOOL program, stillage was discharged directly into riverbeds and caused very serious environmental problems owing to its biologic oxygen demand. However, the high content of nutrients and water in stillage makes it potentially useful for fertilization and irrigation of the soil. This has been a very important solution for some of the dry regions of Brazil. The use of stillage as a fertilizer increased sugarcane productivity, because the physical structure of the soil (mainly porosity) improved the water absorption capacity. As a consequence, agrotoxics and mineral supplements were saved.

Figure 1 - Evolution of yield of sugarcane (t/ha), ethanol (m3/ton of sugarcane), sugar (ton sugar/ton of cane) and content of total recoverable sugar (Ferreira 2002)

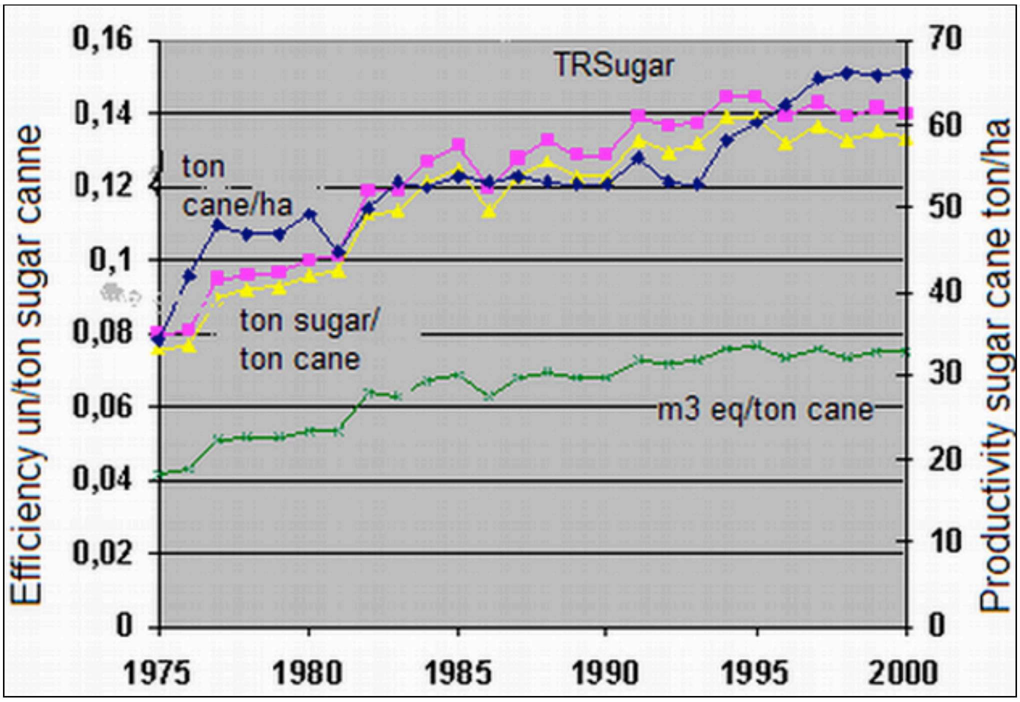
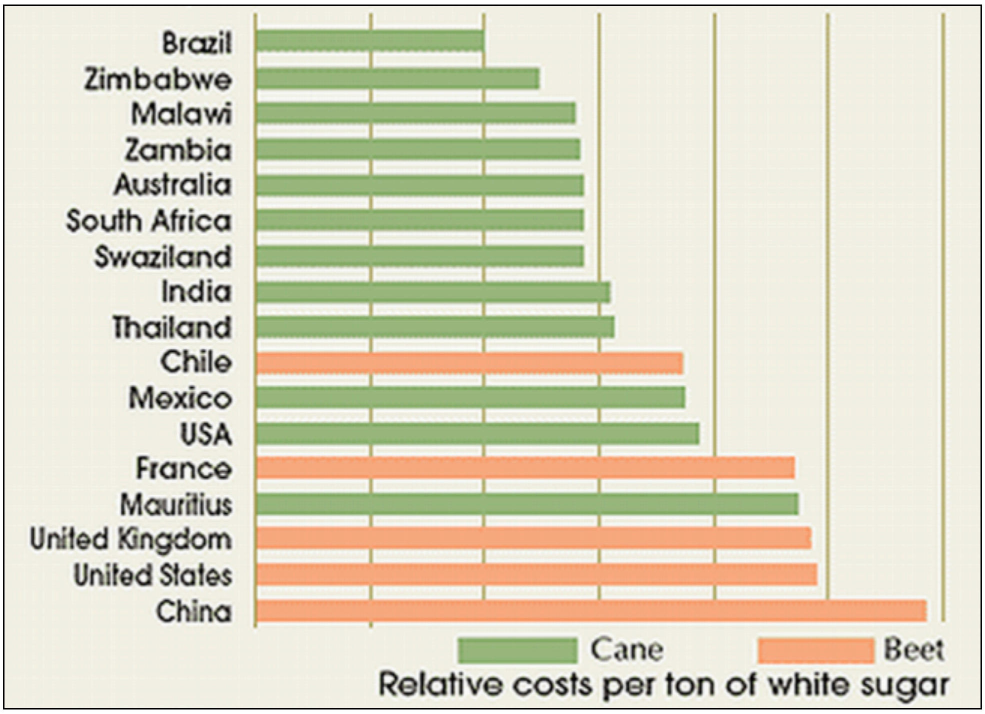


Figure 2 - Lowest cost sugar producers 2003/2004



Source: www.illovo.co.za/worldofsugar/internationalSugarStats.htm
(last accessed on 27/10/2005)

The combined government measures under PROALCOOL led the automotive sector in the country to divert its production to alcohol-powered vehicles. In 1980 the proportion of alcohol-powered vehicles was 30% of the total production, reaching 88% in 1983 and a remarkable 96% in 1986. This is a clear indicator that Brazil developed important technology for ethanol production and created a renewable source of fuel, produced independent of the world petroleum market.

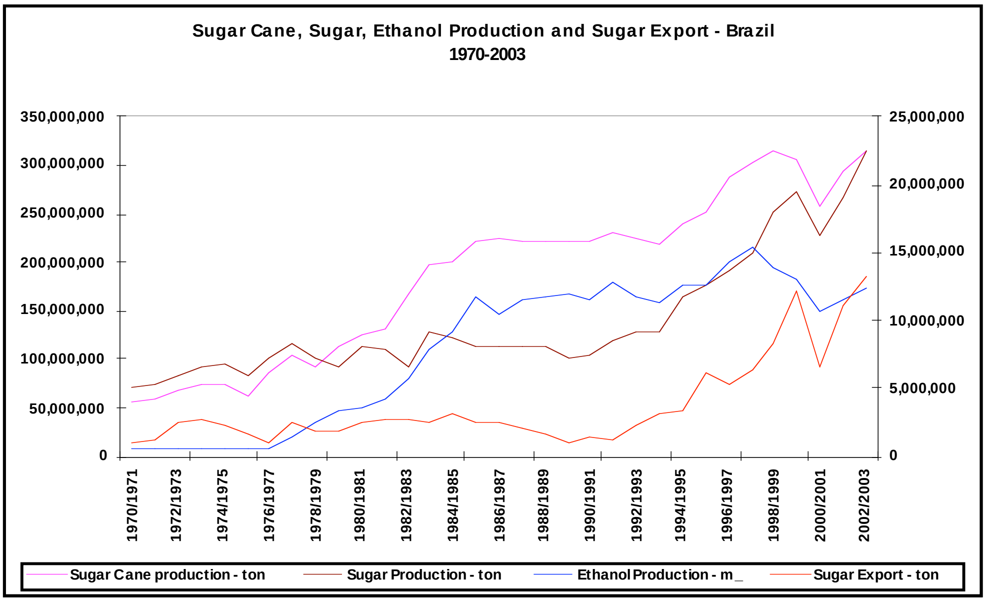
In the mid-80s, however real prices of oil in the international market started to show a deep decline – from over 60 US$/barrel in 1981, it dropped to less than 20 US$/barrel in 1986 (WTRG Economics, 2005[9]). In addition, Petrobras managed not only to find new oil reserves in Brazilian territory but also developed technological capabilities to exploit it both in land and off shore, considerably enhancing Brazilian production of oil. This forced the Brazilian government to reconsider its goals for the incentives to PROALCOOL. From the production side, the rates of establishment of new distilleries came to a halt from the late 80's as government loans at low interests were removed. Existing distilleries were also affected: at least 87 units were totally inactive in the harvesting year 87/88 (BNDES 1995). From the demand side, incentives for purchasing alcohol-powered vehicles, such as lower taxes both for buying and licensing the car and even the ethanol price at the filling stations began to vanish. This new picture, added to technical problems that still remained unsolved in relation to ethanol-powered vehicles led to a set-back of PROALCOOL. In 1990, the number of ethanol-powered vehicles produced dropped to less than 100.000 units, compared to over 700.000 in 1986. Such major policy changes took some years to

[9] www.wtrg.com, last accessed 15/10/2005

have a full impact, and peaked in 1998: the monopoly enjoyed by Petrobras was removed; ethanol prices were liberalized; subsidies paid to hydrous-alcohol producers were reduced from 0.98 reais per liter to 0.45 reais per liter; and subsidies paid to anhydrous-alcohol producers were totally eliminated (USDA, 2001).

The decline in the ethanol demand was joined by a decrease of both international demand and prices for sugar, which started in the mid-80s, as shown in figure 3. The international scene became even worse for sugar in the early 90s when the world production exceeded consumption and led to a steep decline in prices (see figure 4). The consequence was that sugar and alcohol production park, whose capacity had been enhanced in the preceding years, was now partly idle. At the same time, research institutions which had enjoyed considerable financial support during the PROALCOOL and had specialized in the sugar and alcohol production chain were finding it difficult to obtain research funds from other sources and to re-direct their research efforts to other areas.[10]

Figure 3 - Sugar cane, sugar, ethanol production and sugar export in Brazil: 1970-2003



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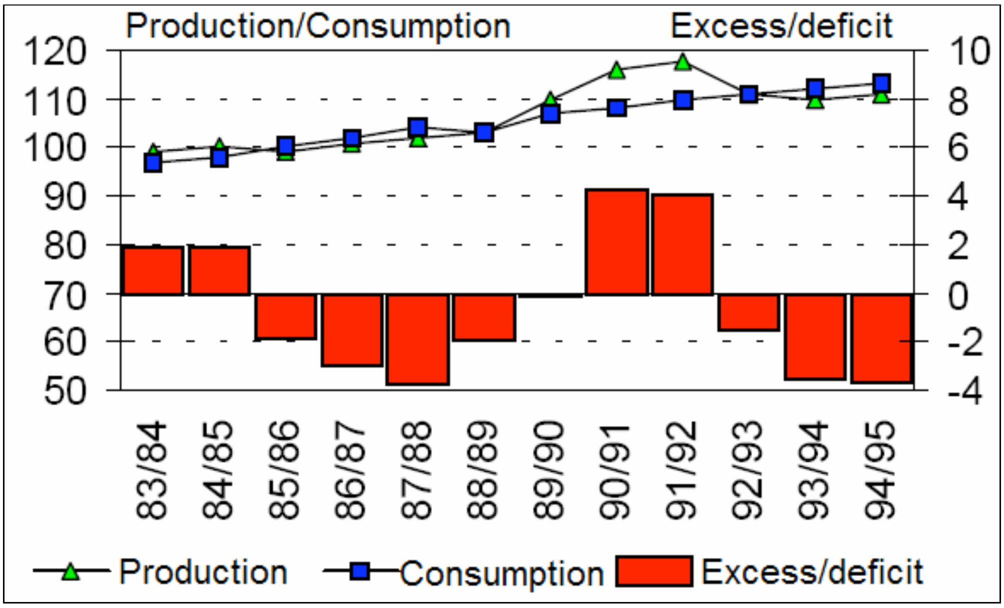
[10] In this period there was a complete restructuring of the sugar cane research system in Brazil. Some traditional government research institutes in the field, such as PLANALSUCAR were closed down. At the same time, sugar cane breeding programs carried out both by Planalsucar and Copersucar were discontinued.

Figure 4 - World production and consumption of sugar: 1983-1995



Source: Landell Mills Commodities Studies (1999)

This was the context in which the idea of producing a biopolymer from sugar was first discussed. Copersucar, a cooperative of sugar and alcohol producers in the state of São Paulo, was pushed by its associates to "search alternative products for the sugar cane production chain, adding value to the products, diversifying the portfolio, in order to make better and more lucrative use of the sugar cane processing industrial park" (CR). For helping them in this task, Copersucar looked for partners in the research system and started discussions with the Institute for Technological Research (IPT). What came out of such discussions that led to the development of a new process to obtain a bioplastic from sugar is what this article is about. In the following section the story begins to be told, with a focus on the social actors involved and their role.

3 Origins and development of the project for obtaining sugar-based plastic: the actors, their profiles and their role

The production process of cane sugar-based plastic in Brazil can be described in two quite distinct phases. The first initiated in 1991 with the approval of a research grant of about 2 million USD to a consortium of institutions, namely the Institute of Technological Research (henceforth IPT), the Institute of Biomedical Sciences of the University of São Paulo (henceforth ICB/USP) and the Technology Center Copersucar (henceforth CTC), each described below. The opportunity for the project appeared as at that moment the Ministry of Science and Technology was implementing the second version of a special S&T funding program called Science and Technology Reform Support Program (PADCT), whose funds came partly from a World Bank loan[11].

PADCT deals with both the university-based research system and the technology-using private sector, and includes several subcomponents which support very specific objectives (matching grants to SMEs, university/industry cooperation, promotion of intellectual property rights enforcement, etc.). PADCT also concentrates its research grants in a set of priority scientific disciplines and technological areas. Biotechnology was one of them and the sugar-based plastic project was then submitted to the Biotechnology sub-program (SBIO) of PADCT II, under a subcomponent called Research, Development and Engineering (PDE) which was managed by FINEP (a government funding agency linked to the Ministry of Science and Technology). PDE aimed specifically at larger projects, involving different agents (universities, government institutes and private firms) and providing support for all necessary steps leading to a potential innovation in product or process – from basic research to technology transfer to the productive sector.

The sugar-based plastic project submitted to and funded by SBIO/PDE/PADCT II through FINEP was entitled "Production of Biodegradable Plastics (polyhydroxyalcanoates) from Sugar Cane via Biotechnological Route" and had the goal to develop a new process for obtaining biodegradable plastic (PHB and its copolymer polyhydroxybutyrate/valerate [PHB-HV]) using sugar cane biomass and its products (mainly sugar) as substrate[12]. The project aimed at the development of the whole process - from the production of efficient microorganisms, fermentation and extraction phases to the transfer of the technology to the productive sector. To achieve this, a division of labor was negotiated and agreed upon between the three institutions involved in the project, namely, IPT, ICB/USP and CTC. Immediately after an agreement was reached between the three partners and as the technological trajectory to be explored was determined (choice of microorganism[13], fermentation, separation, extraction), a patent application was submitted to INPI[14] and was granted (number PI9103116-8[15]) in July 16, 1991. The patent at this point, therefore, protected the conception of a process to obtain PHB from sugar and not yet an existing technology. Granted the patent, the research work started with the disbursement of the first parcel of the grant in 1992.

It is important to mention that one important reason why such institutions got together in this project is because of previous knowledge of each other's work through PROALCOOL. As said in the introduction, PROALCOOL earmarked a fraction of its funds to R&D and the three institutions present here had already

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[11] With negotiations starting in the mid- 80´s, the Brazilian government has succeeded in signing three agreements with the World Bank resulting in loans to fund strengthening and reform of the S&T system. PADCT I (started in 1985), PADCT II (started in 1991) and PADCT III (started in 1998) altogether amount to about 772 million USD, of which 377 million were provided by BIRD/WB loans. These programs had similar objectives but the idea of involvement of the productive sector in S&T activities played an increasing role from the first to the third program. There is not much documentation available in English about the PADCT, but basic information (both factual and analytical) can be found in www.mct.gov.br

[12] Public call for proposals SBIO 01/90-02

[13] IPT and ICB/USP work with three microorganisms: Ralstonia eutropha, Alcaligenes eutrophus and Burkholderia sacchari, http://www.plastico.com.br/revista/pm355/biodegradavel4.htm, pg.3. Ralstonia eutrophus is the bacterium that was genetically modified by ICB/USP and is used by PHB Industrial.

[14] National Institute of Intellectual Property, www.inpi.gov.br

[15] Patent holders are CTC and IPT. The latter entered into agreement with ICB/USP whereby they would equally share IPT's patent rights.

carried out research with PROALCOOL grants, and had either collaborated then or met each other in project workshops and conferences.

Concerning who had the central idea of the project and the initiative to bring the actors together to jointly write and submit a project to PADCT, it is not very clear. Apparently it was CTC who decided to invite IPT for the joint journey and IPT, then, invited ICB/USP as the need for more efficient fermentation organisms was clear. It seems that there was a convergence of interests of both IPT and CTC. The latter, as already said, needed to find alternative uses for sugar cane biomass as well as for sugar (given the decline of PROALCOOL and of the sugar prices in the international market), and IPT needed a new externally-funded project able to sustain the R&D capabilities and personnel it had built under PROALCOOL, and also needed to upgrade its laboratories. A short description of these institutions as well as the role they played in the sugar-based plastic project now seems to be appropriate.

3.1 The Institute of Technological Research (IPT)

IPT is a public research institute attached to the Secretariat of Science, Technology and Economic Development of the State of São Paulo. It was established over 100 years ago with the mission to "meet the S&T demands of the various industrial and engineering sectors and provide technological support to the productive sector"[16]. IPT is organized in multidisciplinary research units called "groupings" (agrupamentos), which are dedicated to develop processes and products in various engineering fields, with special focus on biotechnology, industrial recycling, new materials, petroleum, sanitation, and informatics[17]. Four of such research groupings were involved in the development of sugar-based plastic, namely: biotechnology, organic products, chemical processes and economic assessment.

The biotechnology grouping of IPT appeared in the early 1970s and had two main research lines: production of biogas from domestic waste and from sewage; and alcoholic fermentation, in an attempt to improve traditional processes in operation. They had, then, substantial funding from the Secretariat of Science and Technology of the State of São Paulo and also from PROALCOOL, which started to decline in the mid-80s. However, during almost 15 years of intense research activities, IPT gathered a considerable knowledge base and a critical mass of researchers – about 30 people - doing work on applied and industrial biotechnology. As the grouping was active in alcoholic fermentation it was almost "natural" to collaborate with CTC (the R&D division of the Cooperative of Sugar and Alcohol Producers, as explained below). And this they did during the PROALCOOL and even afterwards, although in much smaller scale.

The participation of IPT in the sugar-based plastic project apparently began when CTC approached the former with the challenge to search for alternative uses for sugar cane biomass and products, as the production chain leading only to sugar and alcohol was thought to be too limited. IPT and CTC spent about a year (1989/1990) searching, discussing and studying alternatives. One that stood out was the production of a biodegradable polymer from Carbon source which, in Europe, where the process had been developed, was thought to be sugar from beets or starch from potato or wheat. In the 1980´s ICI had built and started to operate a plant in the UK to produce this plastic but the price was too high at the time (about 30 USD/kg). It called the

[16] Detailed information on the technical and administrative structure of IPT is availabe at http://www.ipt.br/institucional/organizacao/estrutura/

[17] http://www.ipt.br/institucional/

attention of IPT and CTC, when searching the scientific and patent literatures, that energy was the main culprit for the high prices and that it would be possible to develop a process for the production of a biodegradable polymer from sugar cane biomass since the energy needed would be provided by the bagasse.

In short, according to the interviewees, IPT and CTC decided to bet in the alternative to produce bioplastic from sugar cane biomass, in detriment of other alternatives then considered, for a number of reasons. First, the literature showed the polymer to have interesting characteristics both in terms of its physical properties and biodegradability and also potential industrial applications. Besides, the ecological discourse was quite prominent in the national and international political agenda and they thought they could join it. More importantly, though, they firmly believed they could solve the production bottleneck met by ICI because:

> "the basic raw material we had in mind was sugar (sucrose) and we had it abundantly and at a very low production cost (differently from ICI); and the whole production process was designed to be installed inside a sugar and alcohol production plant so that all raw materials (from fermentation substrate to solvent and energy source) needed for the production of the polymer would be available inside the plant". (PR-Interview)

Thus, this was the main idea developed by the project submitted to PADCT in 1991, after a year of discussion, search, literature review, tasks allocation to different parties, and writing up. IPT took the leadership in project preparation and one of its senior researchers was chosen as the principal investigator, being the technical coordinator to respond for the project.

In the implementation of the project, IPT carried out the following tasks: developed the fermentation process and studied the fermentation parameters (kinetics of growth and production, operational conditions, control and scaling up to 100:1); developed the technology for extraction and purification of the plastic in laboratory scale; built the first casts and proofs with plastic material produced in bench scale to assess the potential utilization; conducted the first biodegradability tests and field trials according to international norms. The bench production unit built at IPT had the fermentation capacity of about 10 liters of sugar syrup and was able to produce 100g of PHB (CR). While developing parameters at this capacity level, IPT had a close interaction with CTC so that the transfer of technology from the former to the latter was constant.

Another important role played by ITP was to identify and invite another partner for the project, namely, ICB/USP, which had a fundamental part in the development of the process as will be described next.

3.2 The Institute of Biomedical Sciences of the University of São Paulo (ICB/USP)

The ICB/USP is represented in the sugar-based plastic project by the Laboratory of Genetics of Microorganisms and Biotechnology. This research group is a pioneer in the field of genetic engineering of yeast in Brazil and has obtained, over the years, many transgenic strains of yeasts with different applications. It is also important mentioning that the University of São Paulo is a public, state supported, university, the most prestigious one in the country and responsible for a considerable part of the mainstream scientific publications produced here.

Researchers from this laboratory were particularly active during the first phase of PROALCOOL during the 70s and early 80s. At that time, they carried out research projects aimed at obtaining strains of Saccharomices cerevisiae able to efficiently produce ethanol from starch, so as to include cassava as a complementary raw material to sugar cane. Given the accumulated knowledge of this group with the production of engineered yeasts as well as their familiarity with the sugar cane production chain, they were easily identified by IPT as important partners and invited to join the consortium.

ICB/USP concentrated on the improvement of the bacterial strains for fermentation. It was well known by them that polymers of the type PHA (polyhydroxyalconoates) are synthesized by a wide range of bacterial strains for the intracellular storage of Carbon and energy under adverse growth conditions and in the presence of excess Carbon sources. Ralstonia eutropha (or Alcaligenes eutrophus) is one of the most studied microorganisms for the production of PHA due to the ease of culturing this bacterium using renewable sources of Carbon and also because this bacterium can attain up to 80% of its dry mass as polymer (Marangoni et all., 2000). This bacterium, however, as naturally occurring, "was not able to produce the polymer using sucrose as substrate", and from the beginning the idea of the project was to use sugar as the raw material – "an abundant and low cost material" (AC). Therefore, the task of ICB/USP was to engineer a bacterium adapted to conditions defined by the project. And so they were able to transfer 5 gene sequences from another bacterium to Ralstonia eutropha and obtained a strain, which was patented, and is still the organism used in the existing production plant.

In the process of selecting and breeding the microorganism, different bacterium strains were screened and various other promising strains were identified that are efficient in producing polymers from sugar cane biomass. One of such, a bacterium isolated from soil of sugarcane plantation with a high yield of PHA was described in 1996 by one of the researchers working at IPT and was deposited at CABRI[18] with the name of Burkholderia sacchari. The innovative characteristic of this bacterium is that it is able to use bagasse as substrate, thus enlarging the possibilities of using different parts of sugar cane biomass as raw material for bioplastic production. A mutant strain of this bacteria as well as the process for obtaining it, with a higher capacity for producing copolymers from sugarcane, was patented in Brazil in 1998. All patents granted in the framework of the project, no matter who deposited it, belong to the consortium of the three institutions – IPT, ICB/USP and CTC. It is to the latter that we now turn our attention.

3.3 The Technology Center of the Cooperative of Sugar and Alcohol Producers of the State of São Paulo – COPERSUCAR (CTC)

Copersucar is a cooperative of 91 members, responsible for the commercialization of over 2.2 million ton of Brazilian sugar in the international market. This makes Copersucar the world's largest exporter of sugar.

In 1970, Copersucar created the Technology Center Copersucar (CTC) dedicated to R&D to attend the technical demands, solve the technical problems and anticipate the innovation needs of its associates. Since its creation, CTC contributed significantly to technological innovation, both major (such as the use of stillage as fertilizer) and incremental, in the entire sugar cane chain. The most visible of such innovations is the creation of new sugar cane varieties, the SP varieties, which are today cultivated in 50% of the area covered with sugar cane crop in the country.

[18] Common Access to Biological Resources and Information

In 2004, CTC was transformed in the Sugar Cane Technology Centre. The acronym CTC was maintained and so was the mission to develop technological contributions to the sector. CTC is no longer an exclusive R&D arm of Copersucar associates, but is open to all interested sugar cane, sugar and alcohol producers, who are willing to become members. The latter today include over 100 sugar mills and cooperatives of sugar cane growers. CTC is financially maintained by contribution of its associates who are granted privileges over the use of R&D results and get technical assistance at reduced prices[19].

The role of CTC in the sugar-based project was crucial of course. CTC developed the technology for extraction and purification of the plastic via solvents. This task was accomplished together with IPT generating the patent PI 9302312-0. The latter also had an important participation in optimizing the fermentation process by investigating and testing the dimension and number of reactors. The main task of CTC, however, was to scale up the laboratory bench process set up at IPT with the latter's assistance. This involved the transfer and adaptation to a pilot unit of intermediate scale (10kg of PHB/batch of fermentation of about 150 liters of sugar syrup) which they had to build and operate at CTC headquarters. In the course of doing so, a number of engineering problems appeared, especially those related to the extraction of the polymer, which were solved jointly by CTC and IPT technical personnel. It was on the basis of the engineering information provided by this pilot unit that it was possible to elaborate a pre-commercial industrial project for the production of 5 ton of PBH/year.

In 1994, the technological process for obtaining the biopolymer PHB, at a bench unit of intermediate scale, was considered to be ready. In addition, CTC had developed a pre-commercial industrial project for PHB production of a pilot production unit that could reach 50 to 60 ton PHB/year when at its fullest capacity, but would start off with not more than 5 ton of plastic/year. At this point Copersucar called its members for a demonstration meeting. The latter aimed at finding partners among Copersucar associated sugar mills where to install the pilot production unit. The idea of this pilot plant was to produce enough PHB to supply the market for tests and trials. Also, this pilot plant was intended as a training facility for the future operators and to provide data both for scale-up and economic evaluation of the process.

Usina da Pedra (henceforth UPedra), a traditional sugar and alcohol producing industry, volunteered to run the risk and went into agreement with Copersucar. The contract established that UPedra would incur the costs of building, buying the necessary equipment and operating the pilot plant and would keep a detailed record of expenditures. If the project were successful, Copersucar would then reimburse the costs giving priority to UPedra to license and use the technology. In case of failure, UPedra would account for the financial losses. The formal contract also had IPT and ICB/USP as signatories as it included payment of royalties for the use of the process patent that is collective held by the three institutions.[20] The time frame of the contract was 5 years from June 1996 (giving UPedra a year to build the unit and start operation), after what IPT was free to look for other partners willing to explore the technology in case UPedra did not commercially produce PBH in 2001.

In 1995, the pilot production unit started operation with technical assistance from CTC and occasional visits from IPT. In 1997 the production capacity reached 8-10 ton PHB/year, that is, 20% of the full capacity of pilot project design. On the one

[19] *http://www.ctc.com.br/php/pagina.php?doc=oque_somos*

[20] The contract says that 3% of the plant revenue is to be paid for used of the technology: 1.5% goes to Copersucar and 1.5% is to be equally shared by IPT and ICB.

hand, there was no point in producing more than needed for tests and trials, on the other, yields were very low due to technical adjustment problems. Despite this, the pilot production unit provided relevant data for an economic assessment of the process. The latter revealed that "the production cost of PHB using the process developed by IPT and CTC and scaled up at UPedra was between 2 and 3 USD/kg. This was extremely favorable when compared to costs estimated by ICI in the 80's (between 20 and 30 USD/kg) and later by Monsanto. The latter bought the plant from ICI, and was able to decrease costs to 14 USD/kg but decided eventually to close it down in the UK" (PR)[21]. This cost estimate was based on two scenarios: an autonomous unit producing 10,000 tons of PHB per year, located outside the mill site, and an integrated unit having the same production capacity. There were clear cost advantages of integrating PHB production with an existing mill, but even for an autonomous PBH plant costs did not go over 3 USD/kg (Rossel et all., 2005).

From 1997 to 2000, the process was considerably improved and partnerships were established between CTC and plastic processors and transformers to search commercial applications for PHB. In 2000, UPedra concluded that the pilot project was successful and wanted to completely get hold of it, license the technology and go commercial. This is when a second phase of the sugar-based plastic process begins. A description of how UPedra proceeded in order to achieve its objectives will now follow.

3.4 Usina da Pedra and PHB Industrial S.A. (PHBISA)

> "To be recognized globally as the first company in the world to produce PHB, from a renewable source, in a commercial scale with clean technology and ecologically correct." (the vision of PHB Industrial) (www.biocycle.com.br/sit.htm)

In the year 2000 the firm PHB Industrial SA was created, the pilot production plant was remodeled, the process adjusted and started operating at the fullest capacity of 50-60 ton PHB/year and its product received the name of Biocycle.[22] From this point onwards, operation control and decision making passes exclusively to PHBISA. Copersucar, as agreed by contract in 1995, has to reimburse the costs incurred by UPedra in the installation of the pilot production unit. Copersucar pays its debt by granting UPedra the right of use, at no cost, to all equipment that belonged to Copersucar and was operating in the pilot plant.

PHBISA is an equitable partnership between two strong and traditional groups in the sugar and alcohol industry – Biagi Brothers (owners of 5 plants, including UPedra) and Balbo Brothers (owners of 3 sugar and alcohol mills). The spoken person for PHBISA maintains that UPedra was from the beginning involved in the search for new alternative uses for sugar cane biomass and they were the ones that prompted Copersucar to embark in the prospecting (SO). This, to a certain extent, explains the readiness of this company to respond to the call for partners from Copersucar in the demonstration meeting mentioned above. The rationale for the decision to embrace the initiative was explained by one of the interviewees:

[21] Biopol, a PBH copolymer compounded resin produced by Monsanto was sold at a price of USD10,00 to 20,00 per kg, depending on grade (Nonato et al, 2001, p.4).
[22] Deposited at the INPI under the number 823034437 in 21/02/2001.

> "Sugar and sugarcane are our business. Biopolymers from sugar represent a business with a future, made with a clean technology, linked to environmental preservation, able to be integrated to the production process already existent in our mills and would make possible to use part of the equipment that traditionally, given the production cycle of sugar cane, is idle at least half of the year". (SO pp.10)

Implicit in this quote is the idea that one important benefit of associating PHB production to sugar mills is the fact that the latter are quite efficient in sugar production and have a long history of accumulated knowledge and competencies in the entire chain from producing sugar cane plantlets free of diseases to high quality sugar.

After the conclusion of an economically viable production process, in 2004, a commercial plant was projected with a capacity of 2,000 ton/year (Pessoa Jr. et al, 2005). The plans are for continuous expansion to 5,000, then to 7,000 and then duplicating to 14,000 ton PHB/year. At this moment it is still regularly operating on a 60 ton/year basis, exporting about 80% of its production, while using the remaining product as samples for developing applications. Production costs are said to be barely covered by sales, as the economic viability of the enterprise requires a 10,000 ton/year plant.

This break-even point has been known at least from 1997. The construction of a 10,000 tons-per-year PHB production unit demands a large investment. Installed equipment for the fermentation plant is estimated in US$ 15,000,000, the extraction and purification unit accounts for another US$ 15,000,000 and utilities for US$ 5,000,000. Land, civil works and buildings are estimated in US$1,000,000 for the fermentation plant, US$ 1,600,000 for the PHB recovering facilities and US$600,000 for the utilities unit. This adds up to a total investment of about US$38,200,000.00 which, allegedly, is equivalent to building a new sugar mill with the capacity of UPedra. PHBISA argues it needs commercial partners to be able to cope with the necessary investment for upgrading to this scale (SO).

The route to develop a viable process in today's scale of 60 ton/year has not been always smooth, in the perception of the protagonists. It required considerable investment both in terms of capital and training of human resources and a long process of learning about the technology. Even more difficult was and has been the search for users of the PHB, so as to establish commercial partners in the longer run. Here seems to lay the crux of the matter: to developed applications for PHB and to create a market for them.

In view of this, it comes as no surprise that PHBISA has been extremely active in putting together a vast array of researchers from different fields, at the national and international level, as well as industrial processors and transformers of polymers, in addition to consultants from diverse areas in order to develop commercial uses of and promote the PHB. Various areas of application have been experimented with and there is rumor that big chemical corporations like BASF have received large quantities of PHB for testing[23]. According to PHBISA spoken person, the following areas of application are under investigation (Ortega Filho, 2003):

- Injection technologies
- Extrusion Technologies/ Thermoformer

[23] BASF is said to have organised an internal seminar that brought together its own R&D personnel with PHBISA representatives to exchange information about PHB. This is taken as an indication of BASF's interest in the product, as the word goes "because PHB blended with biodegradable plastic derived from oil adds desirable features to the latter".

- Cosmetic packaging
- Food packaging
- Packaging for Pesticide
- Agriculture (cups for seedlings)
- Medical area (prostheses, controlled release for medicine, suture, etc)

An informal research network has been established, members of which receive under request, samples of PHB to develop tests for different applications, biodegradability, development of blends and use in different products. This is very important because none of the parties involved in the project up to 2000 had any experience with the production or application of either the PHB or any other kind of polymer. From 1995 till 2000, UPedra operated the unity in order to test the viability of the process, to train the personnel on the job, to fine tune the operational system of the factory and to have samples of the product distributed to concerned researchers and developers. In 2000, with the creation of PHBISA, it was clear that for commercial operation the firm had to develop new skills in product development, commercialization and after-sales assistance. This pointed to materials engineers specialized in resins that could perform trials for the characterization of the product and develop blends for new uses. Such expertise, they found out, was available at the Department of Materials of the Federal University of São Carlos.

3.5 Department of Materials of the Federal University of São Carlos (DEMa/UFSCar)

In 2000 DEMa/UFSCar was invited by PHBISA to become the reference center for product trials and research on applications of PHB. Although the researchers working at that department had never worked with biodegradable resins before, they were very active in traditional polymers and had a high scientific reputation in the field.

The agreement between the two organizations was that PHBISA would send samples of all fermentation batches to be analyzed by DEMa/UFSCar so that a consistent characterization of the product would be achieved. In the last five years, over 250 samples were analyzed and the result is that "the product today has a technical specification... with slight variations given the complexity of the process... It is possible to say that the product has a technical label and commercial features. In short, it is a consistent product" (Interview -JA).

Nowadays, DEMa/UFSCAR is building a 300 m^2 new lab to be called the Centre for Biodegradable Polymers, to work as a reference center for analysis of biopolymers. The lab will be dedicated to trials for product characterization and biodegradability as well as to research on polymeric blends with PHB. The construction of the lab, all equipment and apparatus are covered by PHBISA, who has also hired a full time senior researcher and technicians.

It is important to stress that in the course of the development of Biocycle, from its initial phase in 1990, a network of interested parties was established, became more complex and intensified during the last years. At the beginning, the network was formally constituted by three institutions (IPT, ICB/USA and CTC); in 1995 incorporated one sugar and alcohol producing group (Biagi of UPedra); was officially transformed in a joint-venture in the form of the PHBISA in 2000 (in partnership with another producer, Balbo Brothers); starting to contract works of the DEMa/UFSCAR in the same year. This notwithstanding, a much more complex network of actors has been formed around the project, now an enterprise, constituted by researchers of other universities, industrial polymer transformers, consultants; users of polymers.

It was not possible to identify all institutions and organizations that have asked for samples of PHB for research or for developing applications. The fragmented information indicates that this network is active in exchanging experiences and knowledge about the new process and product. The academic sector is the most visible component of this network and, since academics publish, it is possible to detect the dynamism of the network by tracking scientific publications. A complete list of publications directly linked with the development of Biocycle from the original research project in 1991 to the brand name of today is presented in Annex 1.

In this section we presented the history of the development of a process to obtain biodegradable plastic (PHB) from sugar, focusing on the actors involved and their role. A summary of the main events in chronological order is presented in the box below.

Chronology of the development of PHB

Phase 1: IPT, ICB/USP and CTC. Later on, Usina da Pedra

1989 – CTC approaches IPT to search alternative uses for sugar cane biomass and products
Biodegradable plastic (PBH) is chosen as the route

1990 - IPT elaborates the research proposal "Production of Biodegradable Plastics (polyhydroxyalcanoates) from Sugar Cane via Biotechnological Route" for submission to PADCT (Science and Technology Reform Support Program partly funded with a World Bank loan)

1991 – Project approved by PADCT.
A patent application for the conception of a process to obtain PHB from sugar was submitted to INPI and was granted (number PI9103116-8)

1992 – COPERSUCAR enters into a consortium with IPT (and ICB/USP) to develop the technology for PHB production.
Disbursement of the first parcel of PADCT grant and work begins
IPT develops a bench production unit: fermentation capacity of 10 liters of sugar syrup and production of 100g of PHB

1993 – Copersucar decided to build a pilot unit at its headquarters in the light of the results obtained by IPT – unit capacity: 10kg of PHB/batch of fermentation of about 150 liters of sugar syrup

1994 – Copersucar pilot unit adjusts engineering parameters and is considered a success.
CTC develops a pre-commercial industrial project (pilot production unit)
Demonstration of the CTC pilot unit of the project of a pilot production unit to Copersucar associates
Usina da Pedra volunteers to host the pilot production unit and starts its construction with technical support from CTC

1995 – Pilot production unit at Usina da Pedra starts to operate with technical support from CTC

1997 – Pilot production unit is operating at 20% of its capacity (8-10ton PHB/year).
Copersucar establishes partnerships with plastic processors in Brazil and abroad to search for commercial applications of PHB.

Phase 2: PHB Industrial SA

2000 – Joint Venture between Biagi e Balbo for creation of PHB Industrial SA and the trade name of Biocycle for the product
Plant remodeled to reach fullest capacity of 50-60 ton/year
Department of Materials of the Federal University of São Carlos (DEMa/UFSCar) becomes the reference center for product trials and research on applications of PHB

2004 – Conclusion of an economically viable production process
Project for commercial plant with a capacity of 2,000 ton/year to be expanded to 14,000 tons/year

2000 to 2005
– Technical specification of PHB by DEMa/UFSCar
Search for PHB applications and market creation
Links with polymer processors, transformers, users and academics

But exactly what is the rationale and nature of the process developed and what it consists of has not been described yet. This is what will be presented next.

4 The technological process for obtaining a sugar-based plastic (PHB) in Brazil

The development of new and biodegradable compounds in order to replace hazardous chemicals in industrial activities has been a privileged task for many countries in their R&D activities and among those chemical material, plastic polymers is indeed one of the main targets. One trend of research in this line is starch, and packing material is already at a considerable use in many countries although physical and chemical properties of starch polymers have so far prevented a wider application for other industrial purposes in substitution for plastic. New biotechnologies are under way and according to some scientists, those technologies are almost mature to give polyhydroxibutyrate research and production a boost that could happen through the development of transgenic plants like corn and others, with the ability to synthesize great amounts of the compound which could produce a cost-effective biodegradable polymer for the plastic industry. So far, the main deterrent in the development and adoption of biodegradable substances like plastic as a replacement for traditional and non-biodegradable hydrocarbon compounds is cost effectiveness.

Development of biodegradable plastics is not a new idea. Attempts to develop different kinds of starch based plastics are reported in the literature[24] and elsewhere with varying degrees of success. Table 1 gives some examples of the products obtained from different sources and their characteristics and costs. PHB/V, the focus of our discussion, is listed in the literature at a price of between 7 and 13 USD/kg. This is considerably more expensive than the production costs estimated for the process developed in this case study.

Table 1 - Price of biodegradable plastics obtained form different sources and routes

Price of some biodegradable plastics	
Material	**Cost, $/kg**
Cellophane	5
NC-W/ Cellophane	5
Cellulose Acetate	3-5
Starch/PVOH	3-7
PHB/V	**7-13**
PLA	2-11

NC-W = Nitrocellulose-wax *PVOH = Polyvinylalcohol*
PHB/V = Polyhydroxybutyrate/valerate *PLA = Polylactic acid*
www.ftns.wau.nl/agridata/historybiodegrplast.htm

[24] http://www.ftns.wau.nl/agridata/historybiodegrplast.htm

The biodegradability of plastics depends also on the chemical structure and constitution of the final product and not only on the raw materials used in the production process. Biodegradable plastics may be based either on synthetic or natural resins. Natural biodegradable plastics are obtained from renewable resources (particularly feedstock) such as starch or simple sugars like glucose, fructose and sucrose, the latter being the source of the process presented here. Conceptually, the term biodegradable plastic will be used here to refer to resins that are degraded by biological activity, particularly by enzyme action leading to significant changes in the materials chemical structure. In essence, biodegradable plastics should break down cleanly, in a defined time period, to simple molecules found in the environment such as carbon dioxide and water.[25]

Discussions on the viability of the development of biodegradable plastics have been intense in the last two decades. Despite the limitations on functionality (e.g. sensitivity of humidity for starch, brittleness for polyhydroxybuterate [PHB] and lack of flexibility in producing specialized plastic materials) the advantages of potential uses for specific ends is clearly recognized. The main uses of biodegradable polymer resins are for items for which disintegration after use is a direct benefit. Examples include agricultural mulch films, planting containers and protectors, hay twine, surgical stitching, medicine capsules, and composting bags.

Biodegradable polymer resins hold great promise to compete in the plastic materials and resins market. Between 1987 and 1992, the value of shipments for the overall industry grew from $26.2 billion to approximately $31.3 billion. Based on constant 1987 dollars, this translates into a 4.6070 annual increase.In 1992 biodegradable polymer resins captured less than 5 million pounds or roughly 0.08070 of the plastic materials and resins market (Uri et al, 1995). It is a consensus among experts and analysts that the reason that biodegradable polymer resins are not making greater inroads into this market currently is based on costs.

Technical limitations and high costs not withstanding, as the world enters a century with new priorities for renewable energy and management of waste, with tougher environmental legislation such as extra taxes on conventional non-biodegradable materials, there is renewed interest in biopolymers and the efficiency with which they can be produced. Therefore, an increase in the use of biodegradable polymer resins will require some sort of active government intervention in the market for plastic materials and resins.

Accordingly, as Nonato et al (2001) point out "the development of a biodegradable plastic commodity market may only be feasible if a drastic reduction of the production cost is achieved" (p.2). New technologies in processing are probably the most appropriate route to narrow the cost differential between synthetic plastics and bioplastics, as well as to improve material properties.

Despite being central, reduced costs is not the only condition to be met if biodegradable plastics are to be a commercially viable commodity. It is also most

[25] The American Society of Testing and Materials (ASTM) defines 'biodegradable' as the matter "capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time reflecting available disposal condition" and the biodegradable plastic should break down cleanly, in a defined time period, to simple molecules found in the environment such as carbon dioxide and water.
http://www.deh.gov.au/settlements/publications/waste/degradables/biodegradable/chapter1.html , p.2

relevant that the whole life cycle of the bioplastic is environmentally sound. This is the assumption underlying the process of production of the PHB developed in the case described here. PHB refers to the Polyhydroxybutyrate (PHB) and its copolymers with polyhydroxyvalerate (PHV) that are melt-processable semi-crystalline thermoplastics made by biological fermentation from renewable carbohydrate feedstock – in this case, using sugar. PHB has been described as "the first example of a true thermoplastic from biotechnology" and is also biodegradable. Although quite stable under everyday conditions its degradation rate is very high at its normal melt processing[26].

The integration of the PBH production plant into a sugar mill in the Brazilian context offers unique advantages not only for cost savings but also for an environmentally sound process. First of all advantages is the availability of low price and large quantities of sugar. Brazil, as already mentioned, is not only the largest sugar producing country, but also the lowest cost sugar producing country in the world. Secondly, sugar mills have availability of energy -both thermal and electric- from low cost and renewable sources (bagasse); effective residues and waste disposal management both from the production process and purification and separation process; know-how and facilities for large-scale fermentation process; availability of biodegradable and natural solvents (by-products of ethanolic fermentation) produced inside the sugar mill and used to obtain PHB with a high degree of purity. (Nonato et al, 2001).

The production process of PHB developed in by this case is described by Nonato et al (2001, p. 3), who are literally quoted here:

"The process comprises a fermentation step, in which strains of Ralstonia eutropha […] are aerobically grown to a high cell density in a well-balanced medium consisting of cane sugar and inorganic nutrients. Cell growth is then shifted to PHB synthesis by limiting nutrients others than the carbon source, which is continually fed as a high-concentration sugar syrup. After 45-50 hours, the fed-batch fermentation process is stopped, with a final dry cell mass of 125-150 kg/m^3, containing nearly 65-70% PHB. The fermented medium is thermally inactivated in a heat exchanger, diluted with water, and flocculated. Separation and concentration procedures yield a cell sludge containing 20-30% solids which is then submitted to a multi-stage extraction process with medium-chain-length alcohols in continuous-stirred tank reactors.[27]The extract is purified for cell debris removal and then cooled down to recover a PHB gel. Solvent from the gel is removed by mechanical and thermal concentration. The resulting PHB paste is mixed with water and distilled to remove the remaining solvent. PHB granules are then collected by a sleeve, vacuum dried, compounded and extruded as pellets."

This procedure yields a highly pure polymer by solvent extraction, avoiding the negative environmental impacts of other processes. It is important to highlight once more that the production of PHB from sugarcane was conceived (by IPT and CTC) as a process to be integrated into sugar mill operations, using not only sugar as substrate but also all the facilities the mill can advantageously offer, such as heating and cooling, electrical power, water and effluent treatment and disposal. This is why production costs have been estimated at such a low value when compared to other processes available in the literature.

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[26] http://www.azom.com/details.asp?ArticleID=1881

[27] The latter is a considerable improvement over previously existing processes for PHB obtention that used chlorinated organic solvents that are usually hazardous to human health and the environment. In the process developed here, solvent extraction and purification of PhB is the Isoamylic alcohol, a by-product of ethanol fermentation which offers no risk to human health nor to the environment (Rossel at al, 2005).

The expectations for the development of industrial PHB production by the sugarcane agroindustry are high. According to some experts, there is a large margin for improvement in the current production process, which will result in lower capital and production costs, less generation of solid and liquid effluents and lower consumption of energy. Above all, there is the possibility of using sugar cane bagasse instead of sugar as substrate, which would further decrease production costs[28]. Actually this research line of obtaining a bacterium able of fermenting the pentose and hexose sugar contained in bagasse has also been pursued by IPT and ICB/USP, and a strain with this feature has been obtained and patented (Bramer et allii, 2001). Using this bacterium, however, would imply a number of changes in the process which are not in the agenda at this moment.

5 The financial dimension of the development of the process

Given the number of actors involved in the different phases and activities of process development, an estimate of investment from all parties is not an easy task. Financial resources involved in the First Phase of the process development were estimated by Copersucar and are shown in Table 2. This is probably underestimated because it does not show the amounts spent by UPedra in the establishment and operation of the pilot production plant from 1995 to 2000.

It should be noted that government support was also granted in the form of full scholarships to Master and PhD candidates working in the project. Despite its importance, there is no available information about the amount of money disbursed in the form of scholarships. We know, however, that 15 Masters and 3 PhD degrees were granted to candidates that did their research work in the framework of the project.

Concerning the Phase 2 of the process development, the investment made by PHBISA is treated as business secret. The only information they declare is a flat amount of US$ 9,000,000.00 up to now. In this phase there is also investment from government research agencies. This is the case of FAPESP (the Foundation for Research Support of the State of São Paulo) that granted the amount of US$ 135,000.00 to a research project of DEMa/UFSCar in partnership with PHBISA. Another grant to the same partners has recently been approved, but the amount has not yet been made public. Also, FAPESP as well the federal government agencies like CNPq and CAPES support Master and Doctoral candidates working in different aspects of PHB production and applications in different universities across the country.

[28] *The production cost of PHB is strongly dependent on the price of sugar, which is the major factor, accounting for almost 29% of the final cost.*

Table 2 - Estimated investment in PHB production process development

Organisation	Purpose	Amount (US$)
FINEP	To IPT and ICB/USP, lab equipment, purchasing materials and other research expenses	1.843.666,00
IPT	Own resources for personnel (up to 06/98)	901.778,72
Copersucar	Personnel involved in pilot unit at bench level and preliminary studies	167.124,00
Copersucar	Purchase of equipment and lab materials	44.307,00
Copersucar	Personnel allocated to the project, start-up and follow-up of the pilot production plant at UPedra	2.078.220,00
Copersucar (Usina da Pedra)	Purchase of equipment, materials, assembling, maintenance and operation of the pilot production plant at UPedra	2.476.724,00
Total		7.511.820,00

6 Outputs (academic and proprietary) of the project

Along with the R&D activities developed during the last decade by the different actors, a significant number of qualified professional expertises in the field of sugar-based plastic have been formed. Although, none of the institutions involved in the development of the process had explicitly committed itself to train academic human resources in the framework of the project, the fact that the project involved R&D activities, part of which was carried out by ICB/USP and IPT (both involved in graduate education) as well as by DEMa/UFSCar led naturally to this.

We looked into the databases of the three most important government agencies that grant scholarships for graduate education and found a number of candidates who did their research work on the topic, most of the times supervised by researchers directly involved in the project. This reveals dynamism in the acquisition and production of knowledge on biopolymers in Brazil. It is worth mentioning that before 1990 there were no publications on biopolymers in the country.

The most visible face of the knowledge generated and the human resources trained is revealed by the number of MS thesis, PhD dissertations and scientific publications linked to the project. This is summarized in Table 3.

Table 3 - Outputs of the Development of the Process of Sugar-based Plastic

Activity	Number
MSc Thesis	15
PhD Dissertations	3
Papers National Journals	31
Papers Internacional Journals	31
Patents & Registration	10

7 Summary of the key features of the development of the process

7.1 Absorptive capacity and firm learning

The objective of the project was to produce a bioplastic (PHB) from sugar in an environmentally safe way integrated to a Sugar Mill. This context, with its large quantities of readily available and comparatively low-cost sugar, as well as accessible thermal, mechanical and electrical energy obtained from renewable agricultural sources, was conceived to be the optimum place to introduce a large-scale facility for its production.

The concept of the project itself was innovative. The literature pointed to a series of limitations in the production process of PHB, such as: high costs due to energy requirements, use of toxic solvents, among others. The integrated production process to a sugar and alcohol mill was soon recognized as a clever solution to the limitations, to the point that the idea itself was patented. The process was developed in a successful way. It involved the generation of new basic knowledge (genetic engineering of bacterium strains for fermentation); development of the fermentation an extraction process; engineering and upgrading to pilot units of increasing capacities (from 100g of PHB /batch of 15 liters to 60ton/year). Although not a part of the original project, R&D is now being carried out for developing applications for PHB. In short, the process development was totally based on locally generated knowledge (except for the international literature) and involved all types of R&D activities (from basic research to learning by doing in operating a totally new plant).

This was possible for two main reasons, first of all, because capacity both in R&D and in manufacturing in related fields had already been developed. This exiting capacity included qualified research teams in universities and government institutes; accumulated knowledge in sugar cane, sugar and alcohol production, etc. For instance, the interviewees made clear that the main steps in the production of PHB are fermentation and extraction. Although fermentation for ethanol production is not the same as for PHB production, experience accumulated in the former was of significant use for the latter. The same is true concerning the extraction step of PHB and the processes of sugar crystallization and drying. Therefore, the process development built over existing expertise and skills, despite having to generate new knowledge. To this extent, as well as to the extent that the PHB production unit was within the borders of a sugar mill and managed by people familiar and experienced with sugar and alcohol production, it is reasonable to assume that PHBISA had significant absorptive capacity to assimilate the new process.

The second reason has to do with funding. The research project would not have been developed without the government PADCT grant. Copersucar and PHBISA (the private productive sector) only got involved and invested considerable amounts in R&D and in installing the pilot units because of the favorable results produced in the framework of the PADCT funded project.

7.2 Linkages and interactions

It is clear that process development was possible only because a dense network of institutions and people was formed. From its initial phase in 1990, a network formally constituted by three institutions (IPT, ICB/USA and CTC) established, became more complex and intensified during the last years. It is curious that the three institutions originally involved are a classic triad: academic researchers, government institutes and private sector. It even suggests a "linear" innovation process from basic research to process and product innovation (actually, to a new industry in the country). Now that the process seems to be under control by PHBISA the network formed aims at a different target: product application and market creation. This network is even more complex than the first one, involves academic researchers from various universities but also a large number of private companies – from plastic processors and transformers to users.

7.3 Industrial policy

The government scheme that made this project possible was, strictly speaking, designed as an S&T policy instrument. Although one of the pillars of PADCT was to foster interaction between the academic and the private sector, it is a long way to say that PADCT can be considered part of national industrial policy.

Having said that, if one thinks about the PROALCOOL and the impact it had on various public policies – from energy to transport policy, to agricultural, social (job creation, migration from the NE to the SE regions), environmental and industrial policy (related to the automotive industry, ethanol production, etc) – and if we can agree that the motivation for the PBH project was generated by the rise and fall of PROALCOOL, then it seems reasonable to establish a link between our case and industrial policy. For example, had not the ethanol market been liberalized and the subsidies for sugar and alcohol production eliminated, it is quite possible that the motivation for alternative uses of sugar cane biomass would not have been triggered. But this we can only guess…What can the said beyond any reasonable doubt is that the sugar-based biopolymer (the Biocycle) is a successful case of S&T policy aimed at promoting R&D and technology transfer to the productive sector.

8 Concluding remarks

The case analyzed here provides evidence that given the right conditions, resource-based industries can become knowledge intensive. It also shows that the knowledge and experience and skills accumulated in resource-based activities (sugar cultivation and refining) can be exploited in a different sector (plastics production), in this case, allowing the establishment of a totally new industry.

Success of the sort reported here, however, does not happen "naturally" or "inexorably". It requires pro-active attitudes from all actors, a negotiation of interests, commitment from all parties to the agreement, and government investment. In short, the following aspects should be highlighted as contributing to the success of the sugar-based plastic:

- the relevant actors had already experience of working together during the Proalcool (this points to the difficulties of evaluating impacts of R&D programmes)
- the previous investment of both government and the private sector (represented by Copersucar) on R&D in the sugar and alcohol agro-industry
- The existing research capacity in public sector research system (universities and public research institute)
- the existence of government research schemes to strengthen research capacity in biotechnology and foster linkages between the public and private sectors

Despite being considered successful, it must be remarked that a viable commercial plant of PHB is yet to be built. There are signs that this will happen in the near future, as the expected market for PHB comes true, but this is not yet the case. The future will tell.

9 Annex 1: Relevant scientific production produced in the framework of the development of sugar-based plastic in Brazil

Articles: international journals

BRÄMER, C. O. ; SILVA, L. F. ; GOMEZ, José Gregório Cabrera ; PRIEFERT, H. ; STEINBÜCHEL, A. (2002). Identification of the 2-methylcitrate pathway involved in the catabolism of propionate in the polyhydroxyalkanoate producing strain Burkholderia sacchari IPT 101T and analysis of a mutant with altered composition of the accumulated polyester. Applied and Environmental Microbiology, EUA, v. 68, n. 1, p. 271-279.

BRÄMMER, C. O. ; VANDAMME, P. ; SILVA, L. F. ; GOMEZ, J. G. C. ; STEINBÜCHEL, A.(2001). Burkholderia sacchari sp. nov., a polyhydroxyalkanoate-accumulating bacterium isolated from soil of a sugar-cane plantation in Brazil.. International Journal Of Systematic And Evolutionary Microbiology, England, v. 51, n. 5, p. 1709-1713.

DINIZ, S. C. ; TACIRO, Marilda Keico ; GOMEZ, José Gregório Cabrera ; PRADELLA, J. G. C.(2004). High-cell-density cultivation of Pseudomonas putida IPT-046 and Medium-chain-length polyhydroxyalkanoate production from sugar cane carbohydrates. Applied Biochemistry and Biotechnology, EUA, v. 119, p. 51-69.

GOMEZ, J. G. C. ; COSTA, M. ; PRADELLA, J. G. C. ; SILVA, L F ; TORRES, B. B. ; SCHEMBERG, A. C. G. (2000). Synthesis of Phamcl Containing odd-chain-length Monomers from Sugar Cane Carbohydrate and Propionic Acid by Newly Isolated Bacteria. In: 8TH INTERNATIONAL SYMPOSIUM ON BIOLOGICAL POLYESTERS, 2000, CAMBRIDGE. ABSTRATCTS OF 8TH ISBP, v. 1. p. 1pp.

GOMEZ, José Gregório Cabrera ; ALLI, R. C. P. ; TORRES, B. B. ; BUENO NETTO, C. L. ; OLIVEIRA, M. S. ; SILVA, L. F. (1996). Evaluation of soil Gram-negative bacteria as regards polyhydroxyalkanoic acids yields from carbohydrates and propionic acid. Applied Microbiology and Biotechnology, v. 45, p. 785-791.

GOMEZ, José Gregório Cabrera ; FONTOLAN, V. ; ALLI, R. C. P. ; RODRIGUES, M. F. A. ; BUENO NETTO, C. L. ; SILVA, L. F. ; SIMÕES, D. A. (1997). Production of P3HB-co-3HV by soil isolated bacteria able to use sucrose. Revista de Microbiologia, v. 28, p. 43-48.

GOMEZ, José Gregório Cabrera, RODRIGUES, Maria Filomena de Andrade, FONTOLAN, Valter, ALLI, Rita de Cássia Paro, TORRES, Bayardo Baptista, BUENO NETTO, Celso Lellis, OLIVEIRA, Margaretti Simões, SILVA, Luiziana Ferreira da. Screening of soil bacteria able to accumulate polyhydroxyalkanoates (PHA) from sugar cane derivatives. In: 7th International Congress of Bacteriology and Applied Microbiology Division, IUMS Congresses (International Union of Microbiological Societies), 3 a 8 de julho de 1994, Praga (República Tcheca). Abstracts, BC –7/15 p. 277

GOMEZ, José Gregório Cabrera; SILVA, Luiziana Ferreira da; TACIRO, Marilda Keico; RODRIGUES, Maria Filomena Andrade; SILVA, Elda Sabino; BONOMI, Antonio; SIMÕES, Diogo Ardaillon; BUENO NETTO, Celso Lellis; PRADELLA, José Geraldo da Cruz. Production of biodegradable polymer from sugar cane in Brazil. In: 12TH World Clean Air & Environment Congress and Exhibition, 26 a 31 de agosto de 2001, Seoul (Coréia). IUAPPA - International Union of Air Pollution Prevention and Environmental Protection Association, 2001. CD Rom.

KAPRITCHKOFF, Fernanda M ; VIOTTI, Alexandre P ; ALLI, Rita de Cássia P ; ZUCCOLO, Marisa ; PRADELLA, J. G. C. ; MAIORANO, Alfredo e ; MIRANDA, Everson A ; BONOMI, A. (2000) Enzymatic purification of polyhydroxybutyrate produced by Ralstonia eutropha (aceito para publicação). Journal of Biotechnology.

MEI, L. H. I. Synthesis and characterization of chitosan-PHB blends (2002) Boletin de la Sociedad Chilena de Quimica, Chile, v. 47, p. 529-535, 2002.

NONATO, R.V.; Mantelatto, P.E.; Rossell, C.E.V. (2001). "Integrated production of bodegradable plastic, sugar and etanol". Applied Microbiology Biotechnology, 57,1-5.

OLIVEIRA, Romulo Cesar de, GOMEZ, José Gregório Cabrera, TORRES, Bayardo Baptista, BUENO NETTO, Celso Lellis, SILVA, Luiziana Ferreira da. (2000) A suitable procedure to choose antimicrobials as controlling agents in fermentations performed by bacteria. Brazilian Journal of Microbiology, v.31, p.87-89, 2000.

PESSOA-JR, ADALBERTO; ROBERTO, INÊS CONCEIÇÃO; MENOSSI, MARCELO; DOS SANTOS, RAPHAEL REVERT; ORTEGA FILHO, SYLVIO & PENNA, THEREZA CHRISTINA VESSONI (2005) Perspective on Bioenergy and Biotechnology in Brazil, Applied Biochemistry and Biotechnology, Vol.121-124, 2005, pp 59-70.

PICCOLI, Rosane Aparecida Moniz; GOMEZ, José Gregório Cabrera; BONOMI, Antonio; FERRAZ, Lucas; KAPRITCHKOFF, Fernanda M.; TAKANO, Cintia Y.; MATTOS, Moacir Nunes de; OLIVEIRA, Valter; FONTOLAN, Valter. (1999) Analysis of bioreactor experimental data by the application of metabolic pathway stoichiometry to polyhydroxylakanoate production by Alcaligenes eutrophus. Brazilian Journal of Chemical Engineering, vol. 16, p. 199-204, 1999.

ROCHA, R, C; TACIRO, M.K.;SILVA, L. F., PRADELLLA, J.G.C (2005). Biosynthesis of poly(3-hydroxybutyrate-co-3-hydroxivalerate by Burkholderia sacchari at high yields. Biochemical Engineering Journal, submetido,.

ROCHA, R. C. S. ; TACIRO, M. K. ; SILVA, L. F. ; PRADELLA, J. G. C. (2003). Influence of feeding strategy in the production of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) by Burkholderia sacchari. Journal Of Industrial Microbiology And Biotechnology, n. enviado.

RODRIGUES, M. F. A. ; SILVA, L. F. ; GOMEZ, José Gregório Cabrera ; VALENTIN, H. E. ; STEINBÜCHEL, A.(1995). Biosynthesis of P(3HB-co-3H4PE) from unrelated substrates by Burkholderia sp. Applied Microbiology and Biotechnololgy, v. 43, p. 880-883.

RODRIGUES, Maria Filomena de Andrade, GOMEZ, José Gregório Cabrera, SILVA, Rejane Gomes, ALLI, Rita de Cássia Paro, TORRES, Bayardo Baptista, BARBOSA, Heloiza Ramos, SILVA, Luiziana Ferreira da, OLIVEIRA, Margaretti Simões. Use of different precursors by bacteria to incorporate 3-hydroxyvalerate units in the polymer accumulated. In: 7th International Congress of Bacteriology and Applied Microbiology Division, IUMS Congresses (International Union of Microbiological Societies), 3 a 8 de julho de 1994, Praga (República Tcheca). Abstracts, BC –7/16 p. 277

RODRIGUES, T. C. ; CALIL, M. R. ; GUEDES, C. G. F. ; ROSA, D. S. (2002) Evaluation of Thermal Ageing Effect on the Biodegradability of PHB, PHB-V and

PCL in Soil Compostage.. In: 18 Reunião Anual Polymer Processing Society (PPS-18), 2002, Minho. Anais da 18 Reunião Anual Polymer Processing Society (PPS-18), 2002. p. 1-10.

ROSA, D. S. ; CALIL, Maria Regina ; GUEDES, C. G. F. ; RODRIGUES, T. C. Biodegradability of Thermally Aged PHB, PHB-V and PCL in Soil Compostage. Journal of polymers and the environment, New York, v. 12, n. 4, p. 239-245, 2004.

ROSA, D. S. ; CALIL, Maria Regina ; GUEDES, Cristina das Graças Fassina ; SANTOS, C. E. O. The effect of UV-B irradiation on the biodegradability of poly-b-hydroxybutyrate (PHB) and poly-e-caprolactone (PCL).. Journal Of Polymers And The Environment, Inglaterra, v. 9, n. 3, p. 111-115, 2002.

ROSA, D. S. ; P FILHO, R. ; CHUI, Q. S. H. ; CALIL, M. R. ; GUEDES, C. G. F. (2003). The biodegradation of poly-b-(hydroxybutyrate), poly-b-(hydroxybutyrate-co-b-valerate) and poly(e-caprolactone) in compost derived from municipal solid waste.. European Polymer Journal, Inglaterra, v. 39, n. 2, p. 233-237.

ROSA, D. S. ; RODRIGUES, T. C. ; GUEDES, C. G. F. ; CALIL, M. R. (2003). Effect of thermal aging on the biodegradation of PCL, PHB-V, and their blends with starch in soil compost. Journal of Applied Polymer Science, Inglaterra, v. 89, n. 13, p. 3539-3546.

ROSA, D. S. ; RODRIGUES, T. C. ; GUEDES, C. G. F. ; CALIL, M. R. (2003). The effect of thermal ageing on The Biodegradation of PCL, PHB-V and their blends with starch in the biodegradation in soil compostage. In: Sauro Pierucci. (Org.). Chemical Engineering Transactions. 1 ed. Pisa, 2003, v. 3, p. 907-912.

SÁNCHEZ, Rubén J, SCHRIPSEMA, Jan, SILVA, Luiziana Ferreira da, TACIRO, Marilda Keico, PRADELLA, José Geraldo da Cruz, GOMEZ, José Gregório Cabrera. (2003) Medium-chain-length polyhydroxyalkanoic acids (PHAMCL) produced by Pseudomonas putida IPT046 from renewable sources. European Polymer Journal, v.39, p.1385-1394.

SILVA, L. F. ; GOMEZ, José Gregório Cabrera ; OLIVEIRA, M. S. ; TORRES, B. B. (2000). Propionic acid metabolism and poly-3-hydroxybutyrate-co-3-hydroxyvalerate (P3HB-co-3HV) production by Burkholderia sp. Journal of Biotechnology, Netherlands, v. 76, n. 2-3, p. 165-174,.

SILVA, Luiziana F da ; TACIRO, Marilda Keico ; CARTER, J M ; MICHELIN, M. E. ; PRADELLA, J. G. C. ; GOMEZ, J. G. C. (2004). Poly-3-hydroxybutyrate (P3HB) production by bacteria from xylose, glucose and sugar cane bagasse hydrolysate. Journal of industrial microbiology & biotechnology, EUA, v. 31, p. 245-254.

TACIRO, M K ; PRADELLA, J. G. C. ; GOMEZ, J. G. C. ; MICHELIN, M. E. ; SILVA, L. F. (2002). Production of poly-3-hydroxybutyrate by bacteria from xylose, glucose and sugar cane hydrolysate. In: EUROPEAN SYMPOSIUM ON BIOCHEMICAL ENGINEERING SCIENCE - ESBES, 2002, DELFT. ABSTRACTS OF ESBES-04, 2002. p. 201.

TACIRO, M. K.;Pereira R.P.M.;Pradella J.G.C.;Netto, C.L.B.; Simões, D. (1997). "Poly-3-hydroxibutyrate-co-3- hydroxyvalerate accumlation at differents stagies feeding". Microbiologia 28, 49-53

TAVARES, Lana Zanetti ; SILVA, Elda Sabino da ; PRADELLA, J. G. C. (2004). Production of poly (3-hydroxybutyrate) in airlift bioreactor with Ralstonia eutropha.. Biochemical Engineering Journal, Inglaterra, v. 18, p. 21-31.

VANIN, Mirela, SANTANA, Cesar C., TORRIANI, Íris L. l.(2004) In vitro study of degradation of poly(b-hydroxybutyrate) (PHB) / poly(L-lactic acid) (PLLA) blends in the form of films. Polímeros, July/Sept. 2004, vol.14, no.3, p.187-193. ISSN 0104-1428.

Articles in Brazilian specialised journals

FILIPOV, M. C. O. ; GOMEZ, J. G. C. ; PRADELLA, J. G. C. ; SILVA, L F (2001). Peso molecular de poli-3-hidroxibutirato produzido por mutantes de Burkholeria sacchari afetados no reconsumo este polímero biodegradável. In: XXI Congresso Brasileiro de Microbiologia, 2001, Foz do iguaçu. Resumos do XXI Congresso Brasileiro de Microbiologia. v. 342.

GOMEZ, José Gregório Cabrera ; FONTOLAN, V. ; ALLI, R. C. P. ; RODRIGUES, M. F. A. ; BUENO NETTO, C. L. ; SILVA, L. F. ; SIMÕES, D. A. (1997). Production of P3HB-co-3HV by soil isolated bacteria able to use sucrose. Revista de Microbiologia, v. 28, p. 43-48.

GOMEZ, José Gregório Cabrera, RODRIGUES, Maria Filomena de Andrade, ALLI, Rita de Cássia Paro, SILVA, Luiziana Ferreira da, OLIVEIRA, Margaretti Simões, BUENO NETTO, Celso Lellis (1993) Polímeros bacterianos para plásticos biodegradáveis. In: 2o Congresso Brasileiro de Polímeros, 5 a 8 de outubro de 1993, São Paulo. Anais do 2o Congresso Brasileiro de Polímeros v.1. p.351-356.

GOMEZ, José Gregório Cabrera, SILVA, Lícia M B, SILVA, Luiziana Ferreira da, TORRES, Bayardo Baptista(1997) Produção de PHA contendo monômeros de cadeia média a partir de carboidratos. In: XIX Congresso Brasileiro de Microbiologia, 11 a 15 de novembro de 1997, Rio de Janeiro (RJ). Resumo MI-061, p.184.

GOMEZ, José Gregório Cabrera, SILVA, Luiziana Ferreira da, RODRIGUES, Maria Filomena de Andrade, BUENO NETTO, Celso Lellis, , SIMÕES, Diogo Ardaillon, TORRES, Bayardo Baptista (1996) Rendimento máximo teórico na conversão de fontes de carbono em polihidroxialcanoatos (PHAs) In. XI Simpósio Nacional de Fermentações – XI SINAFERM, 31 de julho a 02 de agosto de 1996, Universidade Federal de São Carlos, SP. Anais, vol. 1. p. 382 - 387

GOMEZ, José Gregório Cabrera; BUENO NETTO, Celso Lellis.(1997) Produção de plásticos biodegradáveis por bactérias. Revista Brasileira de Engenharia Química, vol. 17, pp. 24-29, 1997.

GOMEZ, José Gregório Cabrera; SILVA, Luiziana Ferreira da; PRADELLA, José Geraldo da Cruz; TACIRO, Marilda Keico; SILVA-QUEIROZ, Sonia Regina da; BRETAS, Adriana Fagundes; RANGEL, Fernando Alves; SÁNCHEZ, Rubén J. (2005) Explorando o potencial metabólico de bactérias para a produção de elastômeros biodegradáveis. In: XV Simpósio Nacional de Bioprocessos – XV SINAFERM, 2 a 5 de agosto de 2005, Recife (PE). CD Rom.

KAPRITCHKOFF, F. H. ; ALLI, R. C. P. ; ZUCCOLO, M. ; MAIORANO, A. E. ; PRADELLA, J. G. C. ; MIRANDA, E. A. ; BONOMI, A. (2001) Recovery and purification of polyhydroxybutyrate from Ralstonia eutropha by enzymatic lysis. In: XXI Congresso Brasileiro de Microbiologia, 2001, Foz do iguaçu. Resumos do XXI Congresso Brasileiro de Microbiologia, v. 381.

KAPRITCHKOFF, Fernanda M ; VIOTTI, Alexandre P ; ALLI, Rita Cassia P ; ZUCCOLO, Marisa ; PRADELLA, J. G. C. ; MAIORANO, Alfredo ; MIRANDA, Everson M ; BONOMI, A.(2005) Enzimatic recovery and purification of polyhydroxybutyrate produced by Ralstonia eutropha (aceito para publicação). Journal of Biotechnology.

LOTTO, N. T. ; ROSA, D. S. (2002). Dimensionamento da degradação de PHB e PHB-V, quando submetido em solo compostado e humus, através de variação da rugosidade, ensaios mecânicos e perda de massa.. In: I Encontro de Pós-Graduação Stricto Sensu; Bragança Paulista, 2002, Bragança Paulista. Anais do I Encontro de Pós-Graduação Stricto Sensu; Bragança Paulista. Bragança Paulista. p. 30.

NETO, C.L.B; Gomez, J.G.C. (2001) "Produção de poliésteres bacterianos". In Biotecnologia Industrial , Lima, U.A., Aquarone, E., Borzani, W., Schmidell, W., pp 219-248. Editora Edgard Blücher, São Paulo, SP.

PACHEKOSKI, W. ; AGNELLI, J. A. M. ; ROSA, D. S. (200). BLENDAS DE POLI-HIDROXIBUTIRATO (PHB) COM POLIPROPILENO (PP).. In: 14º Congresso Brasileiro de Engenharia e Ciência dos Materiais (CBCIMAT), 2000, ÁGUAS DE LINDÓIA, SP. Anais do 14º Congresso Brasileiro de Engenharia e Ciência dos Materiais (CBCIMAT), 2000. p. 53301-53308.

PACHEKOSKI, W. ; AGNELLI, J. A. M. ; ROSA, D. S. ; ROSARIO, F. (2001) Envelhecimento em solo de amostras de PHB e da mistura PHB/PP(90/10).. In: IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros., 2001, Gramado- RS. Anais do IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros.. São Carlos-SP : Associação Brasileira de Polímeros, 2001. p. 1264-1266.

PANTÂNO FILHO, R. ; ROSA, D. S. (2002). Avaliação da biodegradação de PHB, PHB-V e PCL em humus orgânico.. In: I Encontro de Pós-Graduação Stricto Sensu, 2002, Bragança Paulista. Anais do I Encontro de Pós-Graduação Stricto Sensu. Bragança Paulista, 2002. p. 28.

PANTANO FILHO, Rubens ; ROSA, D. S. ; CHUI, Queenie Siu Hang ; AGNELLI, J. A. M. (2001) Avaliação da biodegradação de PHB, PHB-V e PCL em solo compostado.. In: IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros., 2001, Gramado - RS. Anais do IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros.. São Carlos : Associação Brasileira de Polímeros, 2001. p. 1244-1247.

PRADELLA, J. G. C. (1997). Poly-3-Hydroxybutyrate-co-3-Hydroxyvalerate Accumulation at Different Strategies of Substrate Feeding. Revista Brasileira de Microbiologia, v. 28, p. 49-53.

PRADELLA, J. G. C. ; SILVA, Luiziana F da ; TACIRO, Marilda K ; GOMEZ, José Gregório Cabrera (2000). Plásticos biodegradáveis a partir de matérias-primas renováveis. Revista Alcoolbrás, Brasil, n. 57, p. 44-45.

PRADELLA, J. G. C.(1995). Etapa Fermentativa do Processo de Produção de Plásticos Biodegradáveis. Publicação IPT, v. 2443, p. 65.

ROSA, D. S. ; CALIL, Maria Regina ; PENTEADO, D. F. (1999) Evaluation of the thermal properties and biodegradability of PCL and PHB submitted in fungus. In: 5o Congresso Brasileiro de Polímeros, 1999, ÁGUAS DE LINDÓIA. ANAIS DO 5o Congresso Brasileiro de Polímeros, 1999. v. 1. p. 1270-1274.

ROSA, D. S. ; CALIL, Maria Regina ; PENTEADO, D. F. (2000). Propriedades térmicas e biodegradabilidade de PCL e PHB em pool defungos. Revista Ciência e Tecnologia, Piracicaba, v. 8, n. 15, p. 75-80.

ROSA, D. S. ; CARRARO, G. (2000) ANÁLISE DO EFEITO DA RADIAÇÃO NA BIODEGRADABILIDADE DE PHB E PCL EM SOLO.. In: VI ENCONTRO DE INICIAÇÃO CIENTÍFICA DA UNIVERSIDADE SÃO FRANCISCO, 2000, BRAGANÇA PAULISTA, SP. v. 1. p. 25.

ROSA, D. S. ; CARRARO, G. ; PENTEADO, D. F. ; FRANCO, B.L.M. (2000) Evaluation of the degradation of LDPE,PCL and PHB when submitted to soil compounds.. Revista Projeções, Bragança Paulista, v. 18, p. 111-118.

ROSA, D. S. ; CHUI, Q. S. H. ; PANTANO FILHO, R. ; AGNELLI, J. A. M. (2002). Avaliação da Biodegradação de Poli (hidroxibutirato), Poli(hidroxibutirato - co-valerato) e Policaprolactona em Solo Compostado. Polímeros: Ciência e Tecnologia, v. 12, n. 4, p. 311-317.

ROSA, D. S. ; GUEDES, C. G. F. ; CALIL, M. R. ; LOTTO, N. T. (2003) Effect of soil temperature on the biodegradation of PCL, PHB and PHB-V. In: SBPMat, Rio de Janeiro. SBPMat. Rio de Janeiro, 2003. p. 116.

ROSA, D. S. ; PANTANO FILHO, Rubens ; CHUI, Queenie Siu Hang ; AGNELLI, José Augusto Marcondes (2002). Avaliação da biodegradação de PHB, PHB-V e PCL em solo compostado.. Polímeros: Ciência e Tecnologia, São Carlos, v. 12, n. 4, p. 312-318.

ROSA, D. S. ; PENTEADO, D. F. ; CALIL, Maria Regina (1999) Avaliação das propriedades térmicas e a relação com a biodegradabilidade em fungos e bactérias de PCL e PHB.. In: II Congresso de Pesquisa e Extensão, da Universidade São Francisco. Bragança Paulista. Bragança Paulista : EdUSF, 1999. p. 44.

SANTOS, C. E. O. ; RODRIGUES, T. C. ; ROSA, D. S. ; CALIL, Maria Regina (2001) O efeito da irradiação UV-B na biodegradação dos polímeros PCL e PHB.. In: IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros, Gramado-RS. Anais do IX International Macromolecular Colloquium e 6o Congresso Brasileiro de Polímeros. São Carlos : Associação Brasileira de Polímeros, 2001. p. 1278-1281.

SCHENBERG, A. C. G. ; VICENTE, E. J. ; NETTO, C. L. B. ; PRADELLA, J. G. C. ; ROSSELL, C. E. V. ; AZZOLINI, M. A. (2000). Produção de plásticos biodegradáveis a partir de cana-de-açúcar através de fermentação bacteriana. (Prêmio ALCATEL à Inovação Tecnológica 2000).

SILVA, L F ; PRADELLA, J. G. C. ; TACIRO, Marilda K ; GOMEZ, Jose G. C. (2003). Produção de plásticos biodegradáveis por via biotecnológica, a partir de matérias-primas renováveis.. Gerenciamento Ambiental, Brasil, v. 29, p. 49-53,.

SILVA, L. F. (2005). Biosynthesis of poly(3-hydroxybutyrate-co-3-hydroxivalerate by Burkholderia sacchari at high yields. Journal of Biotechnology, submetido,.

SILVA, Luiziana F da ; TACIRO, Marilda Keico ; PRADELLA, J. G. C. ; GOMEZ, Jose G C. (2001) Fábrica viva de plástico biodegradáveis. Ciência Hoje, Brasil, v. 29, n. 174, p. 69-71,.

MSc theses

CAMARGO, F. A. (2003) Obtenção, Caracterização e Estudo de Biodegradação de Blendas de Poli(3-hidróxibutirato-co-valerato)/(PHBV) com Lignina de Bagaço de Cana de Açucar. 2003. 89 f. Dissertação (Mestrado em Engenharia Química) - Universidade Estadual de Campinas. Orientador: Lucia Helena Innocentini Mei.

FALCONE, D. M. B. (2004) Influência do PLA, Pó de madeira e outros modificadores sobre o comportamento físico-mecânico do PHB. Dissertação (Mestrado em Ciência e Engenharia dos Materiais) - Universidade Federal de São

Carlos, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Orientador:José Augusto Marcondes Agnelli.

FAVA, ADRIANO. L. B. (1997). Clonagem e Expressao do Regulon Scr Em Alcaligenes eutrophus Visando A Produçao de Polihidroxibutirato A Partir de Sacarose. Dissertação (Mestrado em Ciências Biológicas (Microbiologia)) - Universidade de São Paulo, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Orientador: Ana Clara Guerrini Schenberg.

FILIPOV, M. C. O. (2000) Obtenção e caracterização de mutantes deficientes na despolimerização de polihidroxialcanoatos. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Fundação de Amparo à Pesquisa do Estado de São Paulo. Orientador: Jose Geraldo da Cruz Pradella.

LOTTO, N.T. (2003) Dimensionamento da degradação dos polímeros PHB e PHB-V, quando submetidos a solo compostado e solo simulado, através da variação da rugosidade.. 2003. 81 f. Dissertação (Mestrado em Mestrado Em Engenharia e Ciências dos Materiais) - Universidade São Francisco. Orientador: Derval dos Santos Rosa.

NASCIMENTO, J. F. (2001) " Estudo da processabilidade e da caracterização do Poli (acido 3-hidroxibutirico) - PHB obtido a partir da cana-de-açucar". Orientadores: Mei, Lucia Helena Innocenti and Agnelli, J.A.M., Instituição: Universidade Estadual de Campinas. Faculdade de Engenharia Quimica.

PACHEKOSKI, WAGNER MAURICIO (2001) Desenvolvimento de blendas poliméricas do polímero bio-degradável polihidroxibutirato (PHB) com polipropileno (PP). Dissertação (Mestrado em Ciência e Engenharia dos Materiais) - Universidade Federal de São Carlos, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Orientador: José Augusto Marcondes Agnelli.

PANTANO FILHO, Rubens (2003) Avaliação da biodegradação de poli(-hidroxibutirato), poli(-hidroxibutirato-co-valerato), poli(e-caprolactona) e suas blendas com amido. 2003. 112 f. Dissertação (Mestrado em Mestrado Em Engenharia e Ciências dos Materiais) - Universidade São Francisco. Orientador: Derval dos Santos Rosa.

PATAQUIVA, ALIS M. (2003). Melhoramento das condições da produção de polihidroxialcanoatos em biorreator airlift a alta densidade celular. 140 f. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Orientador: Jose Geraldo da Cruz Pradella.

PEREIRA, ERICA M. (2003). Clonagem de genes do ciclo de 2-metilcitrato e avaliação de estratégias para a obtenção de mutantes prp de Burkholderia sacchari, produtora de plástico biodegradável. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Fundação de Amparo à Pesquisa do Estado de São Paulo. Orientador: Luiziana Ferreira da Silva.

PEREIRA, FABRICIO S. (2002) Estudo do melhoramento da produção de poli-3-hidroxi-4-pentenoato por Burkholderia sp. a partir de sacarose. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Fundação de Amparo à Pesquisa do Estado de São Paulo. Orientador: Jose Geraldo da Cruz Pradella.

ROCHA, RAFAEL S. (2002) Produção de poli-3-hidroxibutirato-co-hidroxivalerato por Burkholderia sp. IPT 189. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Fundação de Amparo à Pesquisa do Estado de São Paulo. Orientador: Jose Geraldo da Cruz Pradella.

RODRIGUES, M.F.A. (1995). "Isolamento e caracterização de bactérias quanto à produção de polihidroxialcanoatos (PHAs) e clonagem dos genes de biossíntese de PHA de Bukholderia sp". São Paulo, Intituto de Ciências Biomédicas, Universidade de São Paulo. (Dissertação de Mestrado).

SILVA, CRISTIANE E. R. (2001). Estudo de Blendas Potencialmente Biodegradáveis de Poli(3-Hidroxibutirato)-PHB e Polietileno de Baixa Densidade (PEBD). 0 f. Dissertação (Mestrado em Engenharia Química) - Universidade Estadual de Campinas. Orientador: Lucia Helena Innocentini Mei.

TAVARES, L. Z. (2002) Produção de polihidroxialcanoatos em biorreator tipo airlift. Dissertação (Mestrado em Biotecnologia) - Universidade de São Paulo, Fundação de Amparo à Pesquisa do Estado de São Paulo. Orientador: Jose Geraldo da Cruz Pradella.

PhD dissertations

DA SILVA, LUISIANA FERREIRA (1998) Estudo do catabolismo de propionato em Burkholderia sp visando o aumento da eficiencia na producao de P3HB-co-3HV - um plastico biodegradavel.

Doutorado em Ciências Biológicas (Microbiologia). Instituto de Ciências Biomédicas, USP/ICB, Brasil. Orientador: Tomomasa Yano

RAMOS, MARIA ELIZABETH MICHELIN (2003) Caracterização de linhagens bacterianas para a produção de poli-3-hiroxibutirato (P3HB) a partir de hidrolisado de bagaço de cana-de-açúcar. Orientador : Tomomasa Yano). Doutorado em Ciências Biológicas (Microbiologia) - Universidade de São Paulo, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Co-Supervisor: Luiziana Ferreira da Silva.

PhD dissertation in progress

Francisco Adão de Camargo. Blendas de Lignina modificada e PHB: Caracterização e Aplicações. Início: 2004. Tese (Doutorado em Engenharia Química) - Universidade Estadual de Campinas. (Orientadora Lucia Helena Innocentini Mei).

Rodrigo Cirillo Baltieri. Desenvolvimento de Formulações de PHB e Amido.. Início: 2000. Tese (Doutorado em Engenharia Química) - Universidade Estadual de Campinas. (Orientadora Lucia Helena Innocentini Mei).

Undergraduate theses

FABRÍCIO CASARIN. Desenvolvimento de blendas de PHB, PHB-V e PCL com amido e suas avaliações de biodegradabilidade. 2004. 0 f. Iniciação Científica. (Graduando em Mecatrônica) - Universidade São Francisco, Conselho Nacional de Desenvolvimento Científico e Tecnológico. Orientador: Derval dos Santos Rosa.

GIULIANO CARRARO. Avaliação do Efeito da Radiação na Biodegradabilidade de PHB e PCL em solo.. 2000. 0 f. Iniciação Científica. (Graduando em Engenharia

Mecatrônica) - Universidade São Francisco, Programa de Bolsa Auxilio Iniciação Científica da Usf. Orientador: Derval dos Santos Rosa.

Patents granted by INPI (National Institute of Intelectual Property) < http://www.inpi.gov.br/>

Description and registration of the Burkholderia sacchari at the CABRI (Common Access to Biological Resources and Information) < http://www.cabri.org/CABRI/srs-bin/wgetz?-id+SLW1R2FGU+-e+[BCCM_LMG:'LMG%2019450']+-qnum+1+-enum+1 >

PI9805116-4 de 14/08/1998 ; Cepa mutante de Alcaligenes eutrophus, cepa transgenica de mutante de Alcaligenes eutrophus e método de obtenção ; Depositante Copersucar/USP, inventor Elisabete José Vicente

PI9806557-2, de 20/11/1998, Cepa Mutante de Burkholderia Sp e método de obtenção de Cepa, Depositante Copersucar/IPT, Inventor Luiziana Ferreira da Silva/J.G C.Gomez.

PI0203550-2 de 28/08/2002 ; Processo de produção e produto de microparticulas biodegradáveis a partir de polímeros tais como mono ou polihidroxialcanoatos em meio aquoso ; Depositante IPT ; Inventor Maria Inês Ré et allii

PI0217356-0 de 24/09/2002 ; Processo de Produção de Polihidroxibutirato e seu copolimero Polihidroxibutirato-co hidroxivalerato a partir da hidrólise de bagaço de cana ; Depositante IPT/Fapesp ; nome do inventor Luiziana Ferreira da Silva et allii

PI9806557-2, de 20/11/1998, Cepa Mutante de Burkholderia Sp e método de obtenção de Cepa, Depositante Copersucar/IPT, Inventor Luiziana Ferreira da Silva/J.G C.Gomez.

PI9805116-4 de 14/08/1998 ; Cepa mutante de Alcaligenes eutrophus, cepa transgenica de mutante de Alcaligenes eutrophus e método de obtenção ; Depositante Copersucar/USP, inventor Elisabete José Vicente

PI9203116-8 de 16/07/1991 ; Processo para produzir polihidroxialcanoatos a partir de açúcares extraido da cana de açúcar ; Depositante Copersucar/IPT ; inventores CelsoLellis BuenoNetto et alli.

PI93022312-0 de 30 06 1993 Processo de extracáo de biopolimeros / Depositante Copersucar IPT , inventores Silas Derenzo et alli.

10 References

BNDES (1995) Setor sucroalcooleiro: álcool. Informe Setorial, 18/10/1995.

BRÄMER, C. O. ; SILVA, L. F. ; GOMEZ, José Gregório Cabrera ; PRIEFERT, H. ; STEINBÜCHEL, A. (2002). Identification of the 2-methylcitrate pathway involved in the catabolism of propionate in the polyhydroxyalkanoate producing strain Burkholderia sacchari IPT 101T and analysis of a mutant with altered composition of the accumulated polyester. Applied and Environmental Microbiology, EUA, v. 68, n. 1, p. 271-279.

BRÄMMER, C. O. ; VANDAMME, P. ; SILVA, L. F. ; GOMEZ, J. G. C. ; STEINBÜCHEL, A.(2001). Burkholderia sacchari sp. nov., a polyhydroxyalkanoate-accumulating bacterium isolated from soil of a sugar-cane plantation in Brazil.. International Journal Of Systematic And Evolutionary Microbiology, England, v. 51, n. 5, p. 1709-1713.

Brasil aperfeiçoa plástico que não agride meio ambiente (2002) http://www.radiobras.gov.br/ct/2002/materia_111002_3.htm

DOANE, W. (1992), New Uses for Starch, in New Crops, New Uses, New Markets: 1992 Yearbook of Agriculture,U.S. Department of Agriculture, Washington, DC.

DOANE, W., SWANSON, C. L., AND FANTA, G. F. (1992), Emerging Polymeric Materials Based on Starch, Materials and Chemicals from Biomass, 12, 197-230.

FERREIRA, C. O. (2002) Avaliação Preliminar do Potencial de Produção de Etanol de Cana de Açúcar. Economia & Energia, n.34, Set/Out. http://ecen.com/eee34/limites_alcool.htm

History of biodegradable plastic
http://www.ftns.wau.nl/agridata/historybiodegrplast.htm. Biodegradable Plastics - Developments and Environmental Impacts (2002)
http://www.deh.gov.au/settlements/publications/waste/degradables/biodegradable/chapter1.html

KNAPP, R. (2003) Brazilian Sugar
http://www.fas.usda.gov/htp/sugar/2003/Brazilsugar03.pdf, 6pp.

MARANGONI, C.; FURIGO-Jr, A. & ARAGÃO, G.M.F (2000) Oleic Acid improves poly(3-hydroxybutyrate-co-3-hidroxyvalerate) production by Ralstonia eutropha in inverted sugar and propionic acid. Biotechnology Letters, 22:1635-1638.

MICHAEL, D. (2003) Biopolymers from crops: their potential to improve the environment. http://www.regional.org.au/au/asa/2003/c/11/michael.htm

NEGRÃO, L.C.P. (2005) Personnal comunication based on data from SPC/DAA/Brazilian Secretary of Agriculture and OCDE.

NOLAN-ITU Pty Ltd (2002) Biodegradable Plastics – Developments and Environmetal Impacts
http://www.deh.gov.au/settlements/publications/waste/degradables/biodegradable/chapter1.html, Australian Government/ Department of the Environment and Heritage.

NONATO, R.V. ; Mantelatto, P.E. and Rossell, C.E. (2001) Integrated Production of biodegradable plastic, sugar and ethano. Applied Microbiol Biotechnology, 57:1-5.

ORTEGA FILHO, S. (2003) O Potencial da Agroíndustria Canavieira do Brasil. Palestra proferida na Faculdade de Ciencias Farmaceuticas-USP em Dezembro de 2003.

PADCT II(1992) Produção de Plásticos Biodegradáveis a Partir da Cana de Açucar por Via Biotecnológica
http://reaact.cesar.org.br:21500/consult/owa/geral_print.formata_

PESSOA-Jr, Adalberto; ROBERTO, I.C.; MENOSSI, M.; SANTOS, R.R.; ORTEGA FILHO, S. And PENNA, T.C.V. (2005) Perspectives on Bioenergy and Biotechnology in Brazil. Applied Biochemistry and Biotechnology; vo. 121-124, pp.59-70.

ROSSELL, C.E.V; NONATO, R.V.; MANTELATTO, P.E and LEAL, M.R.L.V. (2005) Production of Biodegradable Plastic (PHB), Sugar and Ethanol in a Sugar Mill.?

SCHMITZ, T.G.; SEALE, JR J. L.; BUZZANELL, P. G. (2002) Brazil as a Dominant Player in the World Sweetener Market: Do Prices Matter? In Proceedings of the FAO/MOZAMBIQUE SUGAR CONFERENCE Sugar and development in Africa and the world: sustainability, diversification and trade Maputo, Mozambique, 10 – 12 October 2002 Sugar and Beverages Group Raw Materials, Tropical and Horticultural Products Service Commodities and Trade Division Food and Agriculture Organization of the United Nations Rome, 2003, pp32-42

URI, N.D.; BOYD, R,; BEACH, E. D. (1995), Increasing Biodegradable Polymer Use, Technological Forecasting and Social Change 48, 161-176

USDA (2001), Plastic Made More Flexible, More Degradable, http://www.ars.usda.gov/is/AR/archive/apr97/plastic0497.htm (last accessed 20/02/2006).

STUD, T. (1990), Degradable Plastics: New Technologies for Waste Management, Research and Development, March, 50-56 (1990)

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