INCO-Biomat Project

Opportunity study about the processing of cottonseed proteins into materials for agro-industries in South-America

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Foreword

Economic analysis is associated to the following deliverables:

- D23.2 in the Work Package Calendered Materials
- D21.3 in the Work Package Seed Coating
- D20.4 in the Work Package Composite Materials
- D22.5 in the Work Package Thermoulded and extruded Materials

The whole economic analysis is grouped in this report so as to provide a global view on the economic issue of processing biodegradable plastic materials from cotton seed proteins. The opportunity study presented hereby mainly deals with the production of materials before their conversion into plastic goods, in line with the technical achievements within each work package. The production of calendered film being experimented could hardly be scaled up; the calculation of the related production costs (D23.2) would be of very limited interest. The same feeling applies also to the composite materials (D20.4) although pilot production somewhat took place. It seems that there is still room for technical optimization before embarking the evaluation of production of composite materials (D20.4).

Abstract

The prospect of the demand for biodegradable plastics is undoubtly bright. This demand is clearly taking off these recent years in various parts of the world. The price increase of conventional plastics (resulting from crude oil price increase and unfavorable taxing policy) should contribute to sustain the demand for biodegradable plastics. Consequently, the anticipation of 10% for the world market share of biodegradable plastics could make sense in the next future.

It is unlikely that such a market share could be encountered in Brazil and Argentina where the level of plastics consumption is far lower than in economically developed countries. National markets can hardly be the unique outlets for the enhanced production of biodegradable plastics. Exportation must be contemplated; this is yet considered to be the pathway through which Brazil could improve its penetration of European and American markets.

The increasing production of cotton, particularly in Brazil, ensures high production levels of cottonseeds and cotton seed cakes. Level of availability should be modest for additional processing. Cottonseeds are yet used as raw materials in oil industry. Resulting cotton seed meals are yet largely used as animal feeds. Nevertheless, there should remain enough cottonseeds and seed cakes to be used as raw materials for further processing. According to realistic assumptions, there should be enough raw materials for nearly twenty units producing annually 2600 tons of material solution made from cottonseed proteins (COTPROT solution).

The production of COTPROT solution from cottonseeds seems to be price competitive. Fix cost is reasonable since the production derives from an activity extension within existing ginning plants or large cotton farming compounds. Various scenarios of investment plans have been considered, high level of self-financing contributes particularly to lower production costs. This price competitiveness allows considering using COTPROT solution as a substitute in manufacturing biodegradable plastics goods, like films and bags. It is nevertheless not yet sufficient to compete against conventional binding material in seed industry.

The production of plastified materials through extrusion of cotton seed cakes is an opportunity to extend industrial activities within existing oilseeds crushing plants. Its price competitiveness largely depends on the price of glycerol.

Price competitiveness is not sufficient to ensure market penetration. Products derived from using biodegradable plastics materials must comply with the expected technical requirements. This compliance must be assessed on the product-by-product basis, after identification of the products to be manufactured, but this could not be addressed in the framework of an opportunity study.

1. Introduction

Comprehensive analysis is desirable…but not yet feasible

Implementing a comprehensive comparative economic assessment of the production of biodegradable plastics is not an easy issue. Limitations in terms of available data, of connection with the concerned industries and of time prevent us from claiming to implement a global competitiveness assessment in producing biodegradable materials from cottonseeds.

Generally speaking, environmental cost is not reflected in the price we pay for products; this is of particular truth in the plastics case. Conventional plastic material is relatively cheap to manufacture and this is reflected in its inexpensive price. But the costs of disposing plastic goods and of its impact on wildlife are high. This is typical example of negative externality whose cost is not at all internalized in the price we pay for goods we used. In the opposite, biodegradable plastics are assumed to be more environment-friendly, the cost related to disposing goods made from biodegradable plastics is assumed to be lower, and this is a difference which could compensate the higher production cost of these plastics.

Comparative assessment calls for addressing all costs linked to the whole chain of production up to the disposal of conventional and biodegradable plastics. With regard to the costs resulting from collection and recycling as well as the externalities of a plastic-polluted environment, a few scholars argue that conventional plastics should cost as much as biodegradable ones.

Nevertheless, biodegradable plastics do not have only advantages. Although most people mainly take consideration of the positive effect of pollution reduction resulting from degradation, the global effect on environment is more mitigated. Production of biodegradable plastics has negative effect on environment in terms of consumption on non-renewable energy and in terms of CO2 emission. It is hard to claim that biodegradable plastics production would necessarily be far more advantageous than conventional ones. There are various types of biodegradable plastics and their efficiencies fluctuate a lot in terms of non-renewable energy consumption and CO2 emission (annex 1). PHA and PHB are good in terms of energy efficiency as compared to petrochemical polymers. Starch-based polymers come out to offer energy and CO2 emission savings. Biodegradable synthetics, e.g. mixture of thermoplastic starch and polyvinyl alcohol or polycaprolacton are becoming common but their fossil CO2 emission could be high or comparable to petrol plastic. In short, the fact that plastics materials are biodegradable does not imply necessarily that the whole environmental balance will be far much better. The case of bio-fuels reveals that one liter of crude oil is necessary to produce 1.5 liter of bio-fuel. These figures are indications that our attention should not be only attracted by the positive side of a process we favour while overlooking less positive ones.

However, positive impacts on environment while using biodegradable plastics could be more important and diverse than the biodegradation in itself. Some indirect effect accounts. In the case of using biodegradable plastic for mulching, it is stated that soil can be enriched with carbon inducing positive effects on soil structure and soil water retention. These impacts are favorable to crop production and reduce its risk compensating hence the higher cost of biodegradable mulching film.

Life cycle analysis seeks to identify the true environmental impact of a product by considering its environmental effect at every stage of its "life cycle". This includes the impact of extracting the raw materials, processing it into a product, transporting that product, using it and then disposing and/or recycling it. Such an analysis attempts to quantify all of the material and energy inputs and all of the outputs of a product or process. Although desirable, we are not in the position of implementing this kind of analysis for the processing of cottonseed proteins into biodegradable plastics materials.

Limited scope of detailed opportunity study

In the area of assessing the validity of applying new technologies in production, a comprehensive feasibility study is needed to help potential investors make decision. Feasibility study must be very specific to the location contemplated for the production site; it must consider who the investors are, what their financing plan is, along with their commercial strategies. It is clear that it was out of the scope of the INCO Project to achieve this identification of industrial application.

The research works implemented during the INCO Project enabled us to obtain clear ideas on the industrial process and on the input/output flows; we hence can propose a detailed opportunity study to appraise to what extent it could make industrial sense to process cottonseed proteins into biodegradable plastics materials. With reference to the approach advocated by the United Nations Industry Development Organization (UNIDO), this study pertains to introducing an opportunity study to better use an existing resource, namely cottonseeds, a renewable and abundant byproduct of the cotton production. Through this study, we target at estimating the range of the production cost and assess how competitive this cost might be. Of course, this study could not suffice by itself to induce investment decision which requires more detailed feasibility study. We do expect that the results we achieved can help potential investors decide moving for further exploring the feasibility of producing biodegradable plastic from cottonseeds.

The INCO project is dealing with using proteins of cottonseeds through various processes to produce biodegradable plastics materials. The proteins of cottonseeds are either extracted from seed kernels, or from cotton seed meal after the crushing process. Its comes out immediately that the processing into plastics materials could be an extension of the industries activities either within a ginning factory or within an oilseed crushing industry. Two main processes have been considered during the implementation of the INCO Project. Roughly speaking, wet processing leading to a plastics material solution or a dry processing through extrusion leading to granules of plastics materials. Plastics material solution is suitable in particular for film manufacturing, but its use was considered as well as a binding material in the seed coating industry. Granules can fit various manufacturing processes of plastics, in particular through calendaring and injection.

The manufacturing of final plastic goods from cottonseed biodegradable plastics materials were somewhat tested during the implementation of the INCO Project. Simple or composite films were manufactured. Seed coating was adjusted. Plastics calendering was experimented. The research works were however focused mainly on the production of biodegradable plastics materials as raw materials for plastics industries. This report is hence focusing on the opportunity study of producing cottonseed plastics materials as a new biodegradable material. The use of this new kind of material at the level of plastics industries could give rise to many adjustments to improve efficiency, and that we can hardly figure out at this stage. It seems then a little bit premature to extent the economic analysis to the stage of manufacturing final plastic goods.

In compliance with the UNIDO manual on industrial opportunity/feasibility studies, the first part is devoted to a brief assessment of the resources, cottonseeds or related by-products, in Brazil and Argentina. The second and third parts are focused on the assessment of the market demands respectively in the world and in South America. The fourth part elaborates the estimation of the production costs in producing plastics material solution and granules. We will conclude on the prospects of producing biodegradable plastics from using cottonseeds.

2. Relative availability of raw materials for COTPROT production

2.1. Positive trend in cotton production in Brazil and Argentina

During the last decade, Argentina and Brazil have experienced opposed trends in their cotton production. In Argentina, cotton production fell down dramatically and has been divided by four (Figure 1); its share in the world cotton market has become marginal. In the opposite, Brazil succeeded to inverse totally the decreasing trend it faced before 1997 and is setting new production record year after year (Figure 2). This change enables Brazil to export again cotton lint while its production was insufficient to cover the demand of its textile industry. This is essentially the consequence of a remarkable geographic shift of the cotton production, along with modifications of the production techniques. This production has become greatly modernized and highly capitalistic; the management of the production has turned to be very sophisticated in many farms. In this sense, it was like a revolution took place.

Geographic displacement is materialized through the concentration of the cotton production in the Central-West States, representing 70% of the national total (Annex 9), at the expense of traditional cotton producing areas in the Northeast and in the South. New farms were set up on virgin lands, of large sizes and whose cultivation mobilizes advanced technologies just like in USA and Australia. There, farmers are rural entrepreneurs and achieved high yields. The State of Mato Grosso accounts now for more than 45% of the whole Brazilian production. Average yield is high, up to 1200 kg/ha of cotton lint, which is 85% higher than the yield achieved in other Brazilian regions.

Figure 1. Evolution of cotton production in Argentina

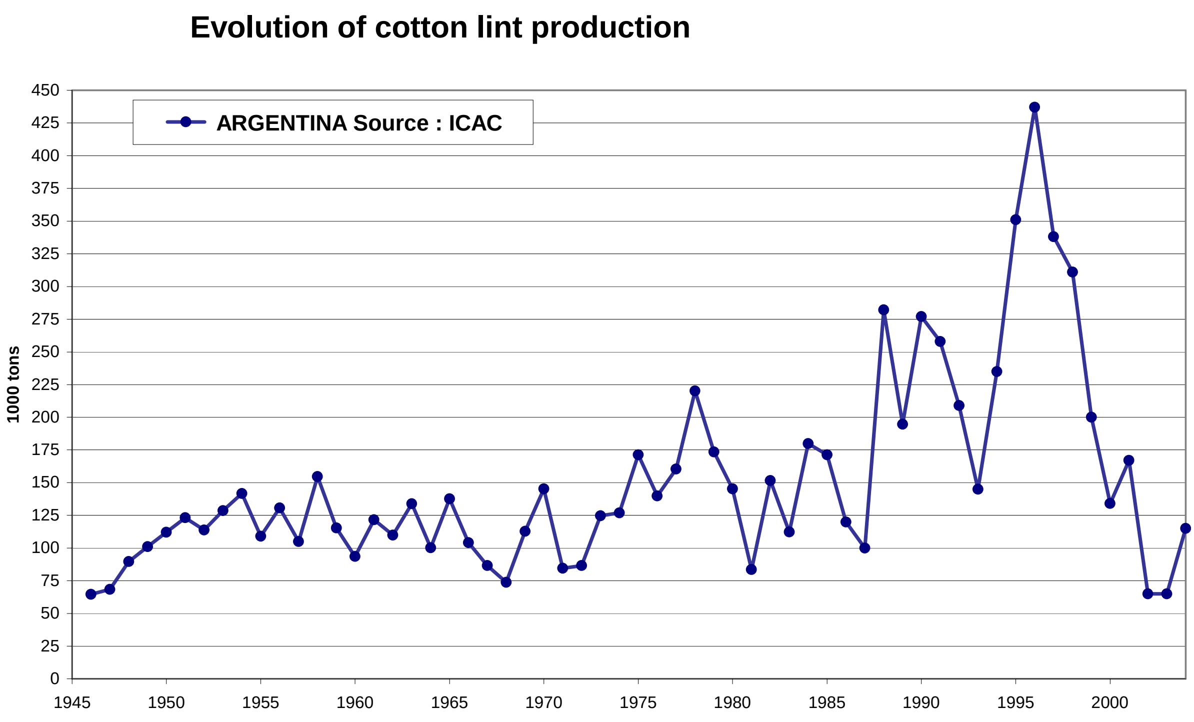
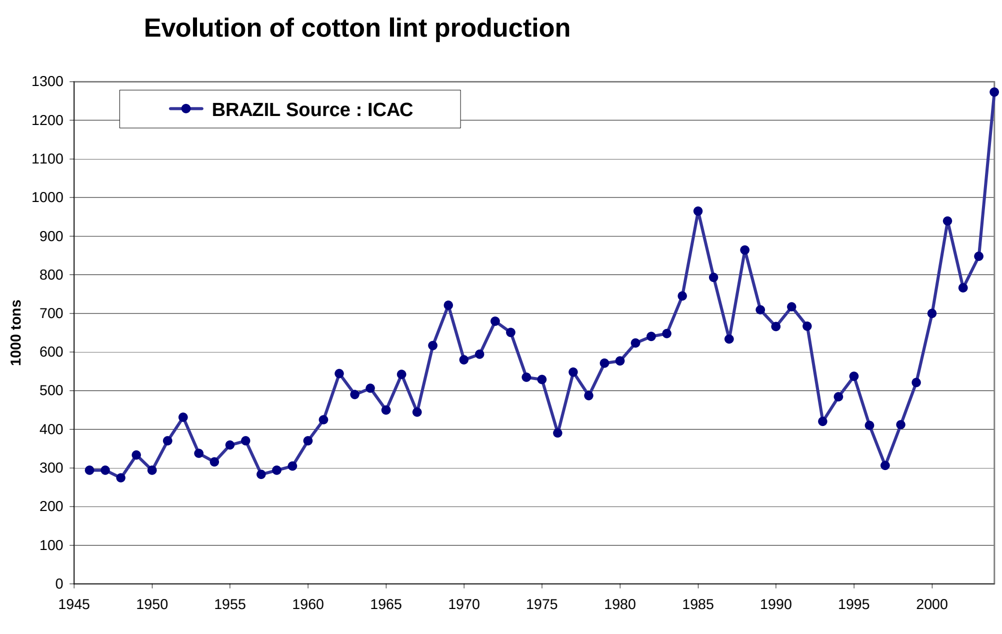


Figure 2. Evolution of cotton production in Brazil



2.2. Differentiated cotton production with large cotton estates

In Brazil, farming differentiation is clearly taking place, opposing family farms and farming estates. These latter could cover thousands of hectares. Maeda is among the largest cotton grower and is reported to cultivate more than 40 000 hectares of cotton. We have not succeeded to accede to statistics about the farming differentiation. It seems that there is no public data on the number of the farming estates, on their average size and their relative share in the whole Brazilian production. What is worth noting at this stage is that there are a few farming estates which grow individually thousands of hectares of cotton. They possess their own mills to gin their cotton and which produce large amounts of cottonseeds suitable for value-adding processing. These farming estates should have potential interest in producing biodegradable plastics from cottonseeds, along with ginning companies which gin through seedcotton collected along numerous cotton producers.

In Argentina, production is concentrated in two major cotton provinces, Chaco and Santiago del Estero, which account for close to 90% of the total cotton area. Cotton farms can be distinguished according to their sizes: the size of "minifundios" is less than 20 ha, the size of small farms between 20 and 90 ha, while large farms are over 90 ha. These groups account respectively for 60%, 25% and 15% of the whole production. These figures mean that large farms in Argentina remain tiny ones as compared to Brazil and that there are seldom cotton producing estates large enough to contemplate the processing of cottonseeds into plastics raw material. This kind of processing should likely take place at the level of ginneries.

2.3. Estimation of potential cotton raw materials for plastics industry

Cottonseeds account for 10% of the world production of oilseeds, largely dominated by soybeans. Cottonseeds are crushed to obtain cotton oil and cotton seed cakes (or seed meals) for animal feeding. For various reasons, cottonseeds are seldom totally crushed. Those which are not crushed could be exported, directly used as animal feed, or used as manures, or simply disposed and burned. At the world level, we can observe that less than 75% of cottonseeds are crushed (Table 1). However, the distribution of the various usages for the remaining share varies a lot between countries and can hardly be assessed. The exportation share of cottonseeds is very limited at the world level, around 3%, but only a few countries are actually exporting.

Crushing of cottonseeds gives about 45% of seed cakes which are destined nearly exclusively to national markets. World exportations concern less than 5% of total cotton seed cakes production.

Table 1. Cottonseeds production and processing in the world

	Cottonseeds					Seed cakes obtained		
	Production	Crushed	exported	% crushed	% exported	Production	Processing ratio	% export
2000	32,96	24,95	1,28	75,7%	3,9%	11,41	45,7%	5,3%
2001	33,48	24,34	1,26	72,7%	3,8%	11,25	46,2%	4,9%
2002	36,62	26,44	1,26	72,2%	3,4%	12,09	45,7%	5,5%
2003	32,84	24,43	1,02	74,4%	3,1%	11,17	45,7%	4,4%

We do not succeed to capture official data on cottonseeds and seed cakes in Brazil and in Argentina, but we can estimate these data from the cotton lint production and the cotton industry processing ratios observed at the world level. Of course, Brazil is producing far more than Argentina. Total cottonseed production is estimated to be around 2 millions tons in Brazil and Argentina (Table 2).

The amount which is not crushed and hence available for various usages, including for potential processing into plastics raw material through the COTPROT technology, is close to 730 000 tons. A substantial share should be kept for animal feeding. If 10% could be diverted from the animal feed market, there should be about 73 000 tons available for alternative usage like plastics industry.

The amount crushed leads to about 600 000 tons of cakes of which at most 5% (or 30 000 tons), corresponding to the exportation share, could be diverted from the animal feed market and be used as raw material for COTPROT production.

Table 2. Estimation of available cottonseeds and cakes in Brazil and Argentina

	Brazil					Argentina				
	lint	Cottonseeds *			Seedcakes	lint	Cottonseeds *			Seedcakes
	production	Production	Crushed	Available	available *	production	Production	Crushed	Available	available *
1995	537	806	524	282	236	351	527	342	184	154
1996	410	615	400	215	180	437	656	426	229	192
1997	306	459	298	161	134	338	507	330	177	148
1998	412	618	402	216	181	311	467	303	163	136
1999	521	782	508	274	229	200	300	195	105	88
2000	700	1050	683	368	307	134	201	131	70	59
2001	939	1409	916	493	412	167	251	163	88	73
2002	766	1149	747	402	336	65	98	63	34	29
2003	848	1272	827	445	372	65	98	63	34	29
2004	1273	1910	1241	668	559	115	173	112	60	50

NB. Assumptions of 65% of cottonseeds being crushed with a processing ratio of 45%
* Estimations deduced from the cotton lint production and the retained ratios

3. Market and demand prospects in the world

3.1. A world of plastic addiction

Our world has become a world of plastic. World consumption was assessed to be five millions metric tons in 1950; it reached 180 millions tons in 2003. To have an idea of how invasive plastic is, it is worthwhile mentioning that one ton of plastic corresponds to 20 000 of 2 liter drink bottles or 120 000 carrier bags of supermarket type.

There are many kinds of plastics. Around fifty groups of plastics and hundreds of varieties are registered. Plastics are grouped into several categories:

- PE accounting for 37% of the whole plastics market in 2000 (LDPE, 21% and HDPE 16%),
- PP for 19% of market share,
- PVC for 17%
- PS/EPS for 9%
- ABS for 3%
- PET for 5%
- and others for 10%

Production estimation for 2005 is 200 millions tons and it is forecasted to be 258 millions tons in 2010. The growth of the consumption has been continuously high and this trend should keep on. The USA has a world production share of 26% in 2000. At the same period, Western Europe reached a market share of 25% and Japan 8% (similar to Germany).

The annual growth is evaluated at 4% in the world, if not 5%. A far higher figure is encountered in emerging countries like China, India and Brazil. As a matter of indication, this growth is five times higher than the one in recycling plastic.

Per capita annual consumption is around 24,5 kg/capita and is forecasted at 37 kg in 2010. There is of course great disparities between countries. Per capita consumption is only 3 kg in India. Indeed, consumption is mainly concentrated in the USA, Europe and Japan. Per capita consumption in Belgium, USA, Italy and Germany is higher than 100 kg/year.

However, owing to the economic development in South-East Asia, this region should account for 40% of the world consumption by 2010. China is yet producing 7% of the world total and this should increase rapidly. We can yet observed that packaging modes in China has become quite similar to the one in Western Europe, with exclusive recourse to plastic and adaptation to smaller portions.

Plastic goods are destined to various economic branches, namely agriculture, furniture, transport, building, material handling, electrical, packaging and other. Packaging accounts the most in the use of plastics while agriculture accounts the less. In terms of consumption growth, the agricultural branch is also showing the smallest figure.

Plastic is also big business. In USA, sales of plastics resins and materials, including basic shapes, amounted to $ 182 billions in 1999 and $ 230 billions in 2004.

3.2. World invaded by plastic bags

Plastic bag is easy and quick to manufacture. There is no wondering why it invades so much our daily life. It is estimated that the world population is using 500 – 1 000 billions of plastic bag per year. Supermarkets are distributing billions of bags yearly: 15 billions in France, 17.5 billions in UK, 6 billions in Australia. And also 1.2 billions in Ireland, but it was before the implementation of a specific tax on plastic bag to discourage its use.

It is clear that there is more concern about the invasion of plastic bags whose impact on environment is negative. Petrol plastics need several hundreds of years to be decomposed, a few statements claim that Polyethylene plastics decompose in one thousand years. This concern leads to more attraction for using biodegradable plastic, an issue we will elaborate below. Recycling can mitigate "white pollution", but when recycling method consists in burning wastes for power, power efficiency remains limited (10% for PE, PET and PS).

It is yet assumed that biodegradable plastics would not be the only answer. Only a small part of plastics go to landfills where decomposition could take place. The amount of plastics our societies consume is an issue to be addressed and it calls for changes in the distribution and in the use of plastics in general and in particular of plastic bags.

Few changes are yet taking place. More and more supermarkets, in particular in France, are no longer distributing plastic bags for unique usage and are encouraging re-usable carrier bags. There is a sound advocacy to turn the back to the use-and-throw consumption mode. Some environment-oriented groups are no longer fighting against using plastic but are concentrating their critics against unique-usage bags. It is beyond the scope of this study to discuss whether this trend will become dominant or not. Nevertheless, if this trend gains ground, it will mean that biodegradable plastic bags will also have to adapt to multi-usage, implying satisfactory strength for that.

3.3. Biodegradable plastics slowly gaining ground

3.3.1. Great Diversity of biodegradable plastics

Biodegradable plastics refer to plastics which comply to quick decomposition criteria: under standard decomposition environment, 60-80 of decomposition is required within 60-180 days.

First production of biodegradable plastics yet dates back to 1907 with the production of cellophane from plant-derived cellulose. Production based upon starch was initiated in 1970s. In the 1980-1990s, production has become more elaborated through grafting two polymeric components which are chemically and physically joined.

Nine approaches in the production of bioplastics are now being identified:

- Direct use of renewable plant material (starch, cellulose, fiber, lignin etc.). In this case, many plant crops have been used: hemp, elephant grass, various natural fibres, wheat, soybean, cassava, potato, various oilseeds, sorghum, sugar cane, switch grass, woody trees. Annex 2 provides a summary of the material sources used and the properties achieved.
- Direct use of renewable animal proteins (milk protein, collagen and gelatine, albumins)
- Genetic engineering to improve plant traits that enhance the efficiency in bioplastics production, in particular to produce more starch.
- Genetic engineering of plants to directly produce biodegradable plastics such as PHA & PHB. Plants involved are alfafa, canola, maize, palm oil, potato, soybean, sugarcane…
- Genetic engineering of animals to directly produce biopolymers such as spider silk
- Microbial conversion (fermentation) of renewable plant material (starch, cellulose, oil, etc.) to biodegradable plastics such as PHA, PHB and PLA
- Fermentation of wastes, to produce biodegradable plastics
- Biodegradable blends, combining in particular natural and synthetic polymers:
    - Starch-protein

- Starch with polyvinyl alcohol and ethylene vinyl alcohol
- Starch with degradable PHBV
- Starch with polycaprolactone blends
- Starch-PLA blends
- PLA and PCL blends
- Aliphatic polyester and poly (vinyl acetate) blends
- Cottonseed and cornstarch blend
- Blend of starch-protein-fibre-lipid
- PHAV and ethyl cellulose blends
- Cornstarch and plastic resin blend
- Soy protein-aliphatic polyesters blend

It is worth noting that there is yet a great diversity of biodegradable materials. It is also worth mentioning that cottonseed has been used so far, through blending with cornstarch. It was Biocorp Inc. which developed a line of disposable cultlery and bags which can decompose through composting within 180 days. These products were used during the Sydney Olympic Games in 2000.

3.3.2. Biodegradable plastics: not yet functionally and economically optimal

While considering the biodegradability, most of the identified bioplastics are yet satisfactory, but this feature is not the only one to be considered for a sustainable production. Materials achieved must be suitable to the properties sought by converting industries. Processing options must be technically feasible. Production and processing must be viable. Life cycle analysis should be satisfactory to convince about the environmental gain provided by biodegradable plastics.

Annex 3 summarizes the attributes and constraints associated to biopolymers obtained through various processing options. It comes out that there is not yet a biopolymer which is functionally ideal and cost-effective enough. PLA seems to be closest by now and could be regarded as the competing reference in the assessment of any new biopolymer. Nevertheless polymer science is entering a very active period and it is reasonable to expect further approaching the functional and economic ideal in the next future.

3.4. Market share is still small

It is not easy to have access to statistics related to the consumption of biodegradable plastics since there are no official statistics available. Insight could only be based upon data provided by professional associations of industries involved in these plastics production.

Clearly, consumption is small. World Demand was estimated to be 20 000 tons in 2000. It is evaluated at around 90 000 tons in 2003 and production capacities are forecasted to reach 136 000 tons. The current consumption is still very small, less than 0.05% of the world plastics market. Even in countries most sensitive to the alternative of using biodegradable plastics, market share remains less than 1%. However, figures we report here yet demonstrate a dramatic increase during the recent years which should indicate a real take-off.

Consumption of biodegradable plastics mainly is a feature of economically developed countries. The USA account roughly for 50% of the whole consumption, Europe ranks second with 40% and Japan for the remaining 10%. The rapid growth rhythm is experienced in most countries. Europe's consumption reached 40 000 tons in 2003, doubling its record of 2001. Australia showed itself very supportive in using biodegradable plastics; this was one of the arguments which enabled it to win the organization of the Olympic Games in 2000. Prospects are bright in this country where it is contemplated that biodegradable plastics could range for 10-30% of PE used for packaging and agriculture.

Along with the consumption increase, the number of countries involved is also augmenting. First-comers like USA, Europe, Japan and Australia are now being joined by India, China, Brazil, Taiwan and South Korea. Chinese production of biodegradable raw materials is reported to be around 40 000 tons, of which 40% are exported. The number of companies involved increased up to around thirty (not including Chinese companies), and most of them were present at the recent International Exhibition on Plastics (Interpack 2005 Dusseldorf, Germany, April 2005).

3.5. *Comparative advantages and current usages*

Biodegradable plastics have been acknowledged of comparative advantages as far as environmental preoccupations are concerned.

- They are felt suitable to natural environments, through goods like agricultural and fishery materials, mulching film, pots for transplanting, fishing lines and nets, civil engineering and construction materials, retaining walls or bags, protective sheets…
- They fit to leisure goods, like golf tees, disposal goods used in fishing, marine sport and mountain climbing,
- They are adapted to cases where recovery and reuse are difficult and where composting of organic waste is effective, like in food packaging, hygienic products,…
- They are also suitable to various products which have to be disposed rather frequently, like pen cases, disposal razors, tooth brushes, cups, trash-bags and cushions.

Biodegradable plastics could also prevail for specific features:

- In cases where slow release is requested, like for materials for drugs, fertilizers, agrochemicals,
- In cases where water retention is sought, like material for tree plantation in deserts,
- In medical use, like suture threads, bone fixation, films, non-woven fabrics,
- When low oxygen permeability is a requirement, like in food packaging and inner coating of cartons for liquids,
- When melting temperature is low, like adhesives for packaging and book-binding and bags

In spite of the potential usages of biodegradable plastics, 50% of these are used for bags. Non-recycled goods account for 25%, coated paper for 15%, food-packaging for 8%, and the remaining for various types of goods.

It appears that biodegradable plastics are still little used in mulching in spite of their suitability. Mulching plastics are a typical example of unsuitability for recycling and for reuse. Recycling is costly because volume to be transported by each user is small while he is far from recycling plant or landfills. It is furthermore costly because of the soil contamination (up to 30-40% by weight) of the plastics which need to be previously cleaned. It is also reported that mulching film has been refused for recycling because of pesticide residues. Reuse can hardly occur because of the deterioration of the plastics even after one season. Incineration is not desirable because of emission of toxic gases while spaces are limited in landfills.

Using conventional mulching plastics might nevertheless remain preferable for farmers who are dealing with great amount of plastics and who do not have constraints in disposing them. Besides, technical constraints are still limiting sufficient degradation which must be both satisfactory in two different microclimates (on and under the soil) within which microbial, light and moisture conditions are distinct. Likely, the expansion of the use of biodegradable plastics in mulching will depend upon administrative or regulatory conditions in disposing plastics and improvement in the degradability of the proposed plastics.

3.6. *Expansion impeded by perception of high cost*

Various studies on the prospect of the expansion of biodegradable plastics pointed out the cost factor as the main impediment. These plastics are viewed as substantially more expensive than conventional plastics. In the technical area, brittleness and/or lack of flexibility are also discouraging from using the existing biodegradable plastics.

With regard to price comparison, it could be considered either at the level of raw materials (resins) or final goods. It is nevertheless not easy to have access to information in particular with regard to raw materials (resins). In the case of plastics, it is neither easy to deal with prices when they are available. Mean prices are indicated for a plastic resin category while there are so many variations which are adapted to specific usages or which give the desired properties. Within the same plastic category, prices could be very different. For example, the price of PS can double when it shows flame retardant properties.

A prospective analysis implemented in 1993 showed clearly that resin prices of most biodegradable plastics were roughly 3 times higher than conventional ones (Annex 4). The information we collected from various sources show that the price gap has remained more or less the same till 2003. If we consider that PLA presents so far the best functionality and economic compromise, its price is 2.5 to 4 times the one of PE.

Table 3. Price comparison of plastics materials

	Price/kg	Year estimation	Source
Conventional plastics			
Petrol plastic	$ 1	1999	BBC News
Polyethylene	$ 0.7-0.8	2001	Rangaprasad & Vasudeo
Polypropylene	$ 0.50	2001	Rangaprasad & Vasudeo
Polyvinyl chloride	$ 0.45	2001	Rangaprasad & Vasudeo
Polystyrene	$ 0.55-0.59	2001	Rangaprasad & Vasudeo
Polystyrene	£ 0.60	2002	Benbrahim
Polyethylene	£ 0.50-0.60	2002	Benbrahim
Recycled HDPE	$ 0.45	2002	Holdings
HDPE	$1.18	2002	Holdings
PP	$0.82-0.89	2000	Holdings
Biodegradable plastics			
Lactic acid based biopolymer	$ 3.3-6.6	2001	Rangaprasad & Vasudeo
PHB based biopolymers	$ 8.8	2001	Rangaprasad & Vasudeo
Starch based biopolymers	$ 5.0-6.3	2001	Rangaprasad & Vasudeo
PLA	£ 2.30-4.50	2002	Benbrahim
PHB/PHBV (Biopol)	£ 6.0-9.60	2002	Benbrahim
Starch-PCL/PVA blends (Mater-Bi)	£ 3.4-4.4	2002	Benbrahim
Starch-Synthetic polymer (Novon)	£ 2.4-2.6	2002	Benbrahim
Starch -based materials	€ 1.25-4.00	2003	Bénézet & Ferry
PLA	€ 2.5-4.0	2003	Bénézet & Ferry
PLA	$3.00-4.00	2000	Holdings
TPS	$2.00-4.00	2000	Holdings
Biodegradable polyesters	$3.50-5.00	2000	Holdings
Lignin-based polymers	$4.55-10.22	2000	Holdings
Cellulose acetate	$6.20	2000	Holdings
Vegemat (maize)	$1.00	2000	Holdings
plant plastic	$ 3-5	1999	BBC News
biomass plastic	$ 1.3	2005	Vegemat

Price comparison should nevertheless be more rigorous. The manufacturing of various goods require using distinct resins offering the needed properties. Comparison should then be made by taking into account the final goods to manufacture and the properties sought. This is a comparison which is not easy to implement.

As material solution made from cottonseed protein (COTPROT) could be contemplated for the conversion into mulching film, it makes sense to have an idea on the current price competitiveness between conventional films and biodegradable plastics films. Mulching film is mainly LDPE film of 30 micron thick, the cost of mulching on hectare is estimated at US$ 250-370. Given that film removal and disposal cost around US$ 250/ha, this means that biodegradable plastics should cost less than 500-620/ha to be price competitive. Since 200 kg of mulching film are needed to cover one hectare, this implies a price range of biodegradable plastics film at US$ 2.00-3.10/kg against US$ 1.32-1.43 for LDPE mulching film or US$ 1.65 for HDPE film.

In the case of carrier bags, it seems that the prices of biodegradable bags made from starch-based polymers are still around five times higher than conventional plastic bags. When considering using fragmentable materials for plastics bags, which can not claim for real biodegradation, prices are claimed to be 1.3 times higher. Food boxes are representing an important market, particularly in South Asia countries: conventional boxes are made from PS, but the price of biodegradable ones is around 80% higher.

Coming back to the price of bioplastics materials, most analysts show themselves to be optimistic about the reduction of the price gap. They observed that biodegradable plastics tend to be less expensive to manufacture while structural increase of crude oil leads to increase the production cost of petrol plastics. This aspect is dealt more in detail below. We anticipate that PLA price should be comprised at US$ 2.5-3.0/kg while PE price should prevail at the US$ 1.3-1.5/kg range.

3.7. Future should be bright

While assessing the prospects for biodegradable plastics, factors which are identified can be categorized into several groups:

- Whole Economic environment
    - ❖ Relative prices of raw materials in producing plastics
    - ❖ Government regulations
- Research
    - ❖ R&D to improve productivity
    - ❖ Economies of scale to reduce costs
- Investment
    - ❖ Investors commitment
    - ❖ Supply chain coordination
    - ❖ Reliable supply and ability to accommodate market growth

We limit ourselves in dealing here with the global economic environment which looks favorable. This is the view of many observers who predict that biodegradable plastics could represent 10% of the whole plastics market, or 15 millions of metric tons, by 2010.

3.7.1. Favorable price trend

Conventional plastics are made from using petrol. It is estimated that 4% of the total consumption of crude oil are destined to be raw material in producing plastics resins during processes which consume additional 3-4% of the total world oil consumption. In short, plastics industry is representing around 8% of the total world consumption of petrol.

Price prospect is favorable for biodegradable plastics because the prices of raw materials they require are expected to be relatively cheaper and more stable than crude oil for conventional plastics.

The price ratio between crop and crude oil was about 50 in the 1970s, it means that average price of crop product was around 50 times than of crude oil. The oil chocks which took place later on modified this situation dramatically. This ratio has turned to around 10 in the 1980s and around 5 in 2000. At the inception of the new century, it was forecasted that this ratio would increase up to the figure of ten, but what happened recently yet infirmed this anticipation.

The crude oil price doubled between 2003 and mid-2005. The world has got accustomed with the idea that crude oil price of US$ 70 a barrel is possible and it is yet prepared that this price could reach US$ 85 in the next future. It is clear that the price ratio will not increase again and will keep on diminishing to the benefit of processors using crop products, in particular bioplastics industries. This price trend of crude oil impacts directly on prices of conventional plastics resins. Short price adjustments being reported recently indicate that the price of PE increased from 25% to 80%. Clearly, PE resin at US$ 1.00/kg belongs to the past and a price range of US$ 1.30-1.50 appears to be more realistic in the next future.

The viability of bioplastics production does not depend only upon lower price level of crop raw materials. Little price fluctuations with crop products as compared to crude oil will be an advantage. Whatever the achievements of the current Doha Round will be, there will be little change with the relative downward stability of agricultural commodities. Prices of bioplastics will be little affected by the raw material cost and will not fluctuate so much. This should be a positive commercial argument for the bioplastics industry.

3.7.2. Favorable policy backstopping

The policy environment is becoming more favorable to using biodegradable plastics through increasing directly or indirectly the price of conventional plastics. This trend is clear in economically developed countries and also in emerging countries and even in a few developing countries.

In Europe, the EU Directive on Packaging and Packaging waste 94/62/EC (the packaging directive) has entered in force. It aims to establish the producer responsibility in dealing with the cost of packaging wastes. In 2005, the new European environmental legislation is implemented aiming to reduce plastics waste disposal. In short, the cost of waste disposal tends to be internalized and reduction of wastes is finally addressed.

This kind of legislation is not specific to western countries. Since 2000, Shanghai municipality (China) passed the rule banning the use of using disposable chopsticks and styrofoam boxes in the downtown restaurant. This concern of plastic pollution is being shared by more and more big cities in China. In France, it was decided that distribution of plastic bags in supermarkets will be totally banned in 2010. This distribution has yet diminished by 20% from 2004 to 2005.

Several governments implement specific taxing policies to discourage the use of conventional plastics bags. In 2001, Ireland implemented a 15 cent tax on each plastic bag. This led to 95% reduction in the bags distributed by supermarkets. The UK government planned also to implement a 9p tax on all shopping bags. Market immediately reacted to the announcement of this tax plan: the anticipation of increasing demand for biodegradable plastics bags led immediately to the price of this latter jump by 3.5p to 42 p.

Recently, Taiwan and Singapore were considering banning plastic bags as well, which Bangladesh yet did in 2002 after it was discovered that plastics bags blocked drainage systems and increased the devastating effects of floods.

In a nutshell, the global environment appears to be favorable to using biodegradable plastics. The anticipation of a market share of 10% in the world by 2010 is not unrealistic. Even a market share of 5% will represent a demand of 13 millions tons, around ten times of the current one. It will be somewhat challenging to adjust the offer accordingly.

With regard to specific products for which cottonseed proteins plastics materials could contribute, mulching film must be considered along with shopping bags. Mulching film is representing a market of 200 000 tons in USA in 2000 and around 0.65-1.20 millions tons in the world. It could be assessed to be around 1 million ton in the world which represents the minimum market bioplastics could capture in the future. It is mainly the PE market which should be the most contested by bioplastics and by the type like COTPROT. If 10% of the PE market could be captured by bioplastics, it would lead to a total amount of around 18 millions tons. Globally speaking, the market for COTPROT-alike bioplastics could be assumed to range from 1 to 18 millions tons in the next decade.

4. Market and demand prospects in Brazil and Argentine

4.1. Significant plastics industries

Plastics industries are becoming important in the two main countries in South America. Turn-over in Brazil reached more than US$ 13 billions in 2004, contributing to 2.26% of the Brazilian GDP. GDP share in Argentine is lower, at most 1% (Table 4). Clearly Brazil is the Plastics giant in the Mercosur Area.

There are more than 8 000 plastics enterprises in Brazil which is almost four times the figure encountered in Argentine. Labor intensity is however distinct between these countries. Workers involved in the plastics industry in Brazil amounted to 236 000 employees in 2004 while they were less than 30 000 in Argentina, almost ten times less. On average, Brazilian plastics plants employ 27 workers, against 12 in Argentine (Table 5). This difference should reflect salaries disparities and should guide the set up of investment plans to address biodegradable plastics.

Table 4. Contribution of plastics industries to GDP

	GDP share Argentina	GDP share Brazil	Industry Share Argentina
1990	1,10%		4,30%
1993	0,80%		3,10%
1997	1,20%		5,00%
2000		1,66%	
2001	1,00%	1,31%	5,00%
2002		1,76%	
2003	0,80%	1,90%	4,90%
2004		2,26%	

Table 5. Number of Plastics enterprises and workers

	Plastics industries		Nber employees	
	Argentina	Brazil	Argentina	Brazil
1986	3 000		36 800	
1990	3 500		38 000	
1996	2 600		30 000	
2000	2 385	6 879	29 000	192 747
2001		7 438		201 682
2002		7 898		218 140
2003	2 253	8 213	27 200	224 941
2004				236 626

4.2. Production for national and Mercosur markets

Production in Brazil and Argentine are mainly destined to satisfy national consumptions. In 2003, national consumption of plastic goods reached 3.8 millions tons in 2003 in Brazil, as compared to 1.1 millions tons in Argentine for the same year (Table 6). International exchanges corresponded to a limited share of national consumptions. Exportation of plastic goods is about 200 000-250 000 tons in Brazil and less than 100 000 tons in Argentine. Importations fluctuates a lot in Argentine during the recent years, in connection with the macroeconomic turmoil this country still faces, they should be stabilized around 100 000 tons. In Brazil, importations are around 250 000 tons during the last five years. Both countries are facing a small deficit in the exchanges of plastics goods, around 50 000 tons in Brazil, and twice less in Argentine.

Mercosur is still the main outlets for plastic goods manufactured in Argentine, for more than 41% of its exportations in 2003, far less than the figure of 62.5% in 2000. In the opposite, Mercosur does not appear to be the main supplier of imported plastic goods in Argentina. Although we do not have the needed data to sustain our feeling, but owing to the recent analysis of the Brazilian plastics industry, we can assume that Mercosur is also the main outlet for Brazilian plastics exportations. A recent study showed that Brazilian plastics represent less than 1% of the total imports in USA and Europe.

Although the sizes of the plastics industries are quite distinct between Argentine and Brazil, the levels of the exchanges of plastics raw materials or resins are rather close. Both countries are importing around 5-600 000 tons of resins. Brazil exports an amount of 8-900 000 tons of resins, which is a little bit higher than the figure of 650 000 tons of Argentine. Both countries have reached the position of net exporters of plastics resins, although at a limited extent, at most 10% of national productions. In Brazil, only 128 plastics firms are registered as exporting plastic products (materials and goods) which represent 1.5% of the total number of firms of the whole plastics industry in the country.

Table 6. Production and exchanges of plastics resins and final goods in Brazil and Argentine

		2000	2001	2002	2003	2004
Argentine	Production of resins(raw material), tons	**885 642**	**1 132 380**	**1 145 939**	**1 201 566**	
	Importations of resins, tons	598 488	507 050	324 084	509 570	
	Exportation of resins, tons	346 792	573 845	666 309	646 838	
	Resins exchanges balance, tons	**-251 696**	**66 795**	**342 225**	**137 268**	
	Apparent consump. Resins, tons	1 137 338	1 065 585	803 714	1 064 298	
	Importation of plastic goods, tons	176 373	167 666	68 996	117 442	
	Mercosur share in import. Plastic goods	22,1%	26,0%	30,3%	33,0%	
	Brazil share in import. Plastic goods	18,6%	20,6%	26,4%	27,4%	
	Exportation of plastic goods, tons	62 077	71 170	81 457	91 597	
	Mercosur share in export. Plastic goods	62,5%	56,1%	43,6%	41,2%	
	Brazil share in export. Plastic goods	35,7%	31,9%	26,3%	25,1%	
	Plastic goods exchange balance, tons	-114 296	-96 496	12 461	-25 845	
	Apparent consump. of plastic goods, tons	**1 251 634**	**1 162 081**	**791 253**	**1 090 143**	
Brazil	Production of resins/raw material, tons	**3 923 326**	**3 704 592**	**3 914 996**	**4 141 223**	**4 410 411**
	Importations of resins, tons	651 763	691 352	681 761	576 886	635 917
	Exportation of resins, tons	687 390	573 620	681 210	901 188	825 849
	Resins exchanges balance, tons	**35 627**	**-117 732**	**-551**	**324 302**	**189 932**
	Apparent consump. Resins, tons	3 887 699	3 822 324	3 915 547	3 816 921	4 220 479
	Importation of plastic goods, tons	252 090	233 832	221 398	230 080	299 982
	Exportation of plastic goods, tons	141 901	155 814	141 688	199 820	247 505
	Plastic goods exchange balance, tons	-110 189	-78 018	-79 710	-30 260	-52 477
	Apparent consump. of plastic goods, tons	**3 997 888**	**3 900 342**	**3 995 257**	**3 847 181**	**4 272 956**

4.3. Significant recycling activity in Brazil

Brazil is particular in its somewhat well developed industry in recycling plastics. There are 300 industrial facilities registered in this recycling activity, providing 20 000 direct employees for a turn-over of R$ 250 million/year.

Recycling is addressing mainly rigid plastics. It is estimated that about 15% of rigid plastics are recycled yearly. Rigid plastics account for 60% of plastic packages in Brazil, the amount recycled corresponds to 200 000 tons per year coming from industry (60%) and urban wastes (40%).

4.4. Reasonable consumption levels

Per capita consumption seems to show some stability, at 30Kg in Argentina and 22kg in Brazil. These figures are quite close to the world average and far lower than those of developed countries (Belgium, USA, Germany, France, Italy…). Probably this consumption level is linked to the economic development levels of these countries or to their distinct consumption modes. An implication is that concern about plastic pollution and willingness to shift to biodegradable plastics should be lower than in western countries. It would not be reasonable to expect biodegradable plastics gaining substantial ground in the short run. Production of biodegradable plastics should target mainly at exportations while national outlet will represent marginal market share. This is in line with recent recommendations acknowledging that only diversification of plastics products, with emphasis on biodegradable ones, will help Brazil to achieve higher exportation volumes to western countries, namely Europe.

Table 7. Per capita consumption

	Argentina	Brazil
2000	30,7	24,4
2001	28,4	21,7
2002	21,2	22,17
2003	30,2	21,75
2004		23,61

4.5. Estimation of bioplastics demand from market segmentation

Like in any country, plastics industries in Argentine and Brazil rely mainly on PE (around 40%) and PP (17-25%). Both countries show higher reliance on PE (Table 8) than the world average (35%), Brazil in addition demonstrate also higher recourse to PP. This situation is favorable for bioplastics material like COTPROT, potential competitors of PE and as well of PP to some extent. PE resin consumption amounts to about 2 200 000 tons (1 700 000 tons in Brazil and 500 000 tons in Argentine). If we consider that biodegradable plastics could capture 1% of this market, this would represent an outlet for 22 000 tons.

Table 8. Distribution of resins used in plastics industries

	2000		2003	
	Argentine	Brazil	Argentine	Brazil
LDPE	24,0%	23,2%	24,0%	22,7%
HDPE	18,3%	18,4%	15,2%	17,1%
Total PE	**42,3%**	**41,6%**	**39,2%**	**39,8%**
PVC	10,1%	18,7%	9,9%	16,1%
PP	16,5%	20,1%	17,0%	24,6%
PS	4,1%	7,5%	5,1%	6,9%
PET	12,5%	10,8%	15,0%	11,3%
Others	14,5%	1,3%	12,9%	1,3%

Like in most countries in the world, packaging is the main consumption sector for plastics. In Brazil, sectors for which biodegradable plastics are expected to have comparative advantage account for almost 20% (11% for disposables, including bags, and 8% for agriculture). These sectors represent a total consumption of 750 000 tons in Brazil. We have not succeeded to obtain similar data in Argentine. Roughly, we can assume the same distribution profile between destination sectors in Argentine. In this case, the sectors of disposables and agriculture would represent 200 000 tons there. In the two countries, the two sectors represent roughly 1 000 000 tons. If we assume a market penetration of 5% in these sectors, this will represent 50 000 tons. This is a second proxy for the estimation of the national market prospects for biodegradable plastics like COTPROT.

Data available in Brazil provide an insight on the market segmentation according to the processes used (Table 9). It is not easy to deduce an estimation of the prospective market for biodegradable plastics like COTPROT. Figures on extrusion and injection provide directly an idea for the use of cottonseed cake or flour through these processes. Plastics goods obtained from extrusion account for 730 000 tons, and 650 000 tons from injection. A market share of 1% would represent a Brazilian outlet of 13 000 tons for plastics obtained from extrusion of cottonseed cake or flour.

Table 9. Market segmentation according to economic sectors and processes

Market segmentation per destination		**Market segmentation per processes**	
Technical components	10%	Rafia	3,0%
Agriculture	***8%***	Lamination	1,0%
Household appliances	5%	Coating	1,0%
Footwear	3%	Expanding	0,8%
Laminated goods	1%	Rotomolding	0,4%
Toys	1%	***Films***	***31,0%***
Packaging	41%	Extrusion	19,0%
Civil construction	12%	Blowing	17,0%
Disposables	***11%***	***Injection***	***16,0%***
Others	8%	***Thermoforming***	***6,0%***
		Others	4,0%

4.6. *Bioplastics production yet engaged*

According to our cautious assumptions based either from the consumption level or from the market segmentation, the national markets for biodegradable films and bags should be comprised between 22000 and 50 000 tons. The market for extruded materials is estimated at 13 000 tons.

Biodegradable plastics production is yet engaged, at least in Brazil. We did not succeed to capture the whole picture of this production. A big company is yet running, called A PHB Industrial S.A. and owner of the trade name Biocycle. It is an ambitious industry destined to produce PHB from sugarcane and which claims the objective of becoming the biggest PHB producer in the world. Although little information is available through its web site, this company seems to produce mainly for external markets.

5. Assessment of production costs

In this part, production costs are estimated for the production of biodegradable plastics materials made from proteins of cottonseeds. The cost of producing granules of plastics materials from the extrusion of cotton seed cakes will be appraised separately. It will not be addressed the production cost in producing film or other final plastic goods, because the associated processes are not yet optimal or they not yet formatted for a real industrial production.

All cost estimations are made in the Brazilian case. In Brazil, the potential of technology adoption appears to be higher in terms of availability of raw materials and of the number of entrepreneurs yet involved in the agro-industries. As the reader will notice, the processing of cottonseed proteins could both call for stakeholders yet involved in agro-industries, namely ginners or oilseeds crushers, and for plastics industry players. Of course, the calculations we conducted could be easily adapted to the Argentinean case.

5.1. Production cost of COTPROT solution from cottonseeds

5.1.1. Production: extension of activities within farm compounds or ginneries

In Brasil, cotton production results, but not exclusively, from large farms ("Fazendas" in Brazil), covering thousands of hectares leading to thousands of cotton bales. Most of these farms possess their own factories to gin seedcotton into cotton lint and cottonseeds. This organization is actually common to commercial farming in many cotton producing countries, except in small scale family farming. The resulting feature to retain is that there is yet extension of agricultural activities towards industrial activities. This characteristic means that there is rationale to extent the industrial activities within "Fazendas", furthermore when this extension enables to add value to the cottonseed byproduct which is readily and steadily available along the ginning season. This is also valid at the level of ginneries which process the seedcotton production from many farms.

Production of COTPROT solution will then be considered in the framework of extending the industrial activities within cotton producing large compounds like "Fazendas". Positive economic implications are manifold. The cost associated with the supply and handling of cottonseeds will be reduced at minimum. Existing infrastructures will allow limiting investment to specific production equipments. Labor cost should be limited as well since the extension of production activities to cover the whole year instead of only cropping season. These features are items of comparative advantage with reference to specific production facilities of biodegradable plastics.

5.1.2. Process inputs/outputs ratio

The implementation of the INCO project enabled to proceed to COTPROT production at the laboratory level in order to clarify the processing yields at every production stage. The outcomes of the research works conducted by Dr Paulo Sobral's team are summarized in the following flow chart (Figure 3). Basically, the process is based on mixing 21.0% of cottonseed flour, 4.0% of TEA (Triethylen Amine) and 75.0% of water to obtain a dispersion solution which leads to COTPROT solution (26° Brix) with a processing yield of 23% at the laboratory level. The production capacity is 691.24 kg/hour, which corresponds to 967 tons per year, considering a production season of 1400 hours. This processing capacity is achieved without the target of optimizing the use of the equipment capacities.

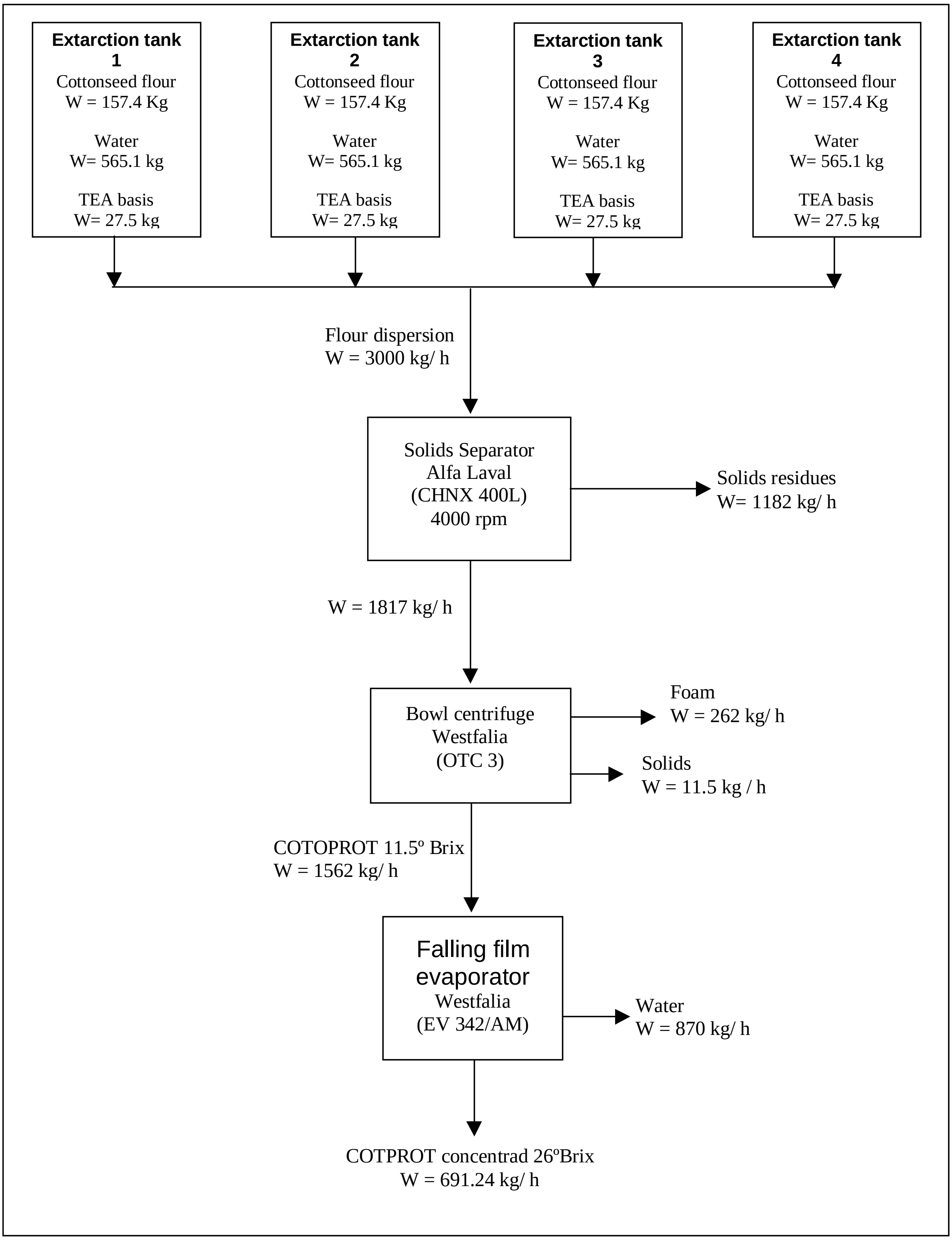
A better capacity, implying economies of scale to reduce unit cost, could be expected from an optimizing approach provided that realistic information could be obtained on the needed equipments in terms of investment cost, capacities, energy consumption. This is what we succeeded to obtain thanks again to the contribution of Dr Paulo Sobral and his connection in the industrial world.

It is worth noting that the laboratory processing could start from using cottonseed flour while at the cotton producing compounds, the raw material available is cottonseed. The implication is the need to integrate a de-husking stage, a grinding stage and a sieving stage to obtain flour at the desirable fineness.

Table 10. Individual equipment capacities and costs

	Investment cost	Currency	Capacity	Energy consump. KWh/hour
Dehusking machine	1 500 000	US$	min. 8000 tons cottonseeds	15
Grinder, JF5	2 600	R$	1200 kg/h	5 to 11
Vibrating Sieving machines	20 000	R$	1000 kg/h	1 to 2
Dispersion tanks with mixers	22 000	R$	750 kg/h of solution	2
Solids separator	350 000	US$	10000 kg/h	22
Bowl centrifuge	100 000	R$	2200l/h	1,1
Evaporator	650 000	R$	2200 kg/h	20

Figure 3. COTPROT production, laboratory scale



5.1.3. Optimization of production equipment

The information obtained on the needed equipment is summarized in Table 10. Optimization follows the criteria of using at most the specific equipment whose impact on unit cost appears to be the highest. According to the information we collected, this is the case of the solid separator whose capacity is very large. This leads us to consider an equipment set which should be closer to optimality (Table 11). This equipment is the one we consider in the calculation to estimate production costs. Of course, more information on the capacities and costs of the needed equipment by prospecting further along equipment suppliers could lead to another set of production equipment. This should be considered at the stage of feasibility study.

Table 11. Retained equipment set for CORPROT production

Equipment	Unit input capacity (kg/hour)	Number of units
De-husker	6 000	1
Kernel grinder	1 200	3
Vibrating sieve	1 000	2
Disersion tank	157	12
Solid separator	10 000	1
Bowl centrifuge	2 200	2
Evaporator	2 200	2

The break down of the flow movements at each production stage is shown in Annex 5 and is summarized in Table 12. The retained production equipment corresponds to an annual production capacity of 2602 tons of COTPROT 26° Brix, from using 7406 tons of cottonseeds.

Table 12. Synthesis on inputs/outputs balance per year

Inputs		Outputs	
Products	Total amount, tons, KWh, unit	Products	Amount, tons/year
Cottonseed	7 406	COTPROT 26° Brix	2 602
TEA	414	Solid residues	4 449
Cans	14 000	Foam	986
water	8 509	water	3 275
steam	2 685		
electricity	238 857		

Assuming a ginning outturn of 40% fibre, 56% of seeds and 4% of wastes, the total amount of 7406 tons of cottonseeds correspond to 13225 tons of seedcotton. Referring to an average of 3000 kg/ha to 4500 kg/ha of seedcotton, the total amount of cottonseeds could be obtained from the cultivation of 2900-4400 ha of cotton. As far as we know, this size of cotton production is not uncommon within some existing commercial farming compounds in Brazil. In other words, the production scheme of COTPROT solution could apply to several existing cotton industries or ginning companies. The size of national demand we estimated gives prospect for 8 to 19 production units of the one we are assessing. Of course, there is room for far more units of this kind when external markets are being considered.

5.1.4. Equipment plan retained for cost estimation

In the area of specific production equipment, in addition to the machines yet mentioned, wastes management is contemplated through aerobic or anaerobic basins. Workers are associated to each production stage so that the investment in conveyers to move products from one stage to another is of limited scale.

In the area of infrastructures, investment should be also minimal within an existing plant. Several infrastructures yet exist or are yet set up:

- Land for the extension of the industrial activities
- Roads and lorries for the transportation of inputs and outputs

- Storage facilities of cottonseeds and outputs
- Administration offices and facilities
- Energy supply at the needed amount
- water supply at the needed amount
- vapour supply amount (this assumption is more debatable)

The only additional infrastructure pertains to the set up of a production workshop.

Since the production implements a new technology, we integrate technology transfer cost along with the provision of technical assistance. We retained the formula of having these costs being paid once for all at the launching of the production. The value we retain is only indicative.

The whole investment scheme is summarized in Annex 6. Part of the investment can be provided locally, notably in terms of infrastructures and of a few non-specific production equipments. Local investments are less sensitive to fluctuation of exchange rates. The main exchange rate is against US$ we consider at the level of 2.4 (2.4 R$ for one US$). Imported investment accounts for more than 85% of the total (Table 13). Depreciation period is ten years, this is common assumption with regard to production equipment in Brazil. Although there are some investments in infrastructures (buildings) for which depreciation should be longer, but whose share in the total investment is small, we adopt a global 10-year period for depreciation for matter of simplicity.

Table 13. Investment split-down

Infrastructures invest. In R$	**400 000**
Local Production equipment in R$	**1 111 800**
Local investment in R$	**1 511 800**
Local investment in US$	**629 917**
Imported Prod. equipment in $	**2 600 000**
Technology transfer	**1 200 000**
Imported investment in US$	**3 800 000**
Total investment in US$	**4 429 917**
Depreciation in US$	**442 992**

We assume that self-financing covers 50% of the whole investment costs of US$ 4.4 millions. The remaining investment is financed through a 5-year credit. Credit is expensive in Brazil, we consider a credit rate of 2% per month which corresponds to 26.8% per year.

Material and labor costs (Table 14) are obtained along people involved in cotton and chemical industries and can be assumed to be very close to reality.

Table 14. Material and labor Unit costs

		Unit cost in R$
Cottonseed	ton	280
TEA	ton	9960
Cans for Cotprot (200kg)	Unit	40
water	ton	1,3
steam	ton	100
electricity	Kwh	0,23
Workers	man-month	1200
Supervisor	man-month	3000

5.1.5. Production cost insufficiently attractive

Details of the cost estimation are summarized in Annex 7. Total unit cost amounts up to US$ 1.73/kg. It is not easy to compare this cost to unit price of competing plastics resins since we must integrate the final products to manufacture and the associated processing yields. If we roughly assume that 1 kg of COTPROT solution gives 0.3 kg of film (through the process of film casting), while 1 kg of PE resin give more or less 1 kg of film, we need to compare the cost of 3 kg of COTPROT solution (around US $ 5.2/kg) with the price of 1 kg of PE resin (US$ 1.30-1.50/kg). In this case, COTPROT is showing the same price disadvantage than most of the existing biodegradable plastics and even less competitive than PLA which is considered to be the best technical and economic compromise among existing biodegradable plastics to compete against PE (price forecasted at US$ 2.5-3.0/kg in a next future).

It is noteworthy that raw material accounts for a rather small share of the production cost while TEA represents a big share of the total unit cost. It seems that this is a factor to take into consideration in the sensibility calculations.

Table 15. Production cost of COTPROT solution

COTPROT Prod. Tons	2602	Total cost, US$	Unit cost US$/kg	Unit cost, %
Fix cost	Direct fixed capital	1 436 138	0,55	32%
	Labor	55 500	0,02	1%
	admin. & Overhead	50 000	0,02	1%
	Total	**1 541 638**	**0,59**	**34%**
Variable cost	Raw materials	864 033	0,33	19%
	Other consumables	1 951 676	0,75	43%
	Utilities	139 386	0,05	3%
	Total	**2 955 095**	**1,14**	**66%**
Total cost		**4 496 733**	**1,73**	100%

We do not succeed to obtain information on PLA production at industrial level, but the one we obtained for the production of PHB is helpful to underline the potential specific advantages of COTPROT production. PHB is obtained from fermentation process for which various bacteria can be used. Alcaligenes eutrophus appears so far to be the most effective. Fermentation leads to PHB which has to be recovered from the solution. Two recovery modes are generally considered, either by using surfactant –hydrochlorite or by dispersion treatment with chloroform. The production costs (Table 16) refers to an annual production of 2850 tons which is quite similar to the one we consider for COTPROT here.

Table 16. Production cost of PHB, 2850 tons/year

	Product Recovery mode 1		Product Recovery mode 2	
	Unit cost $US/kg	Cost share, %	Unit cost $US/kg	Cost share, %
Direct fixed capital	1,51	27%	2,12	23%
Labor	0,49	9%	0,61	7%
admin. & Overhead	0,23	4%	0,29	3%
Raw materials	2,33	42%	3,58	39%
Other consumables	0,00	0%	0,65	7%
Utilities	0,47	8%	1,66	18%
Waste treatment/disposal	0,56	10%	0,25	3%
Total	**5,58**	100%	**9,16**	100%

Product recovery mode 1 : by surfactant-hydrochlorite Source: Holdings, 2004
Product recovery mode 2 : by dispersion treatment of chloroform

Source: Holdings, 2004. Quoting the costs extrapolated from the data obtained and extrapolated in a Korean laboratory

Production cost clearly is high in this case (and higher than tne one obtained by the recent Brazilian company A PHB Industrial S.A.). In the PHB case, bacteria efficiency and recovery mode can impact greatly on production cost. This is an indication of efficiency gain in the next future in this kind of production. In PHB production, raw material accounts a lot while other consumables are negligible. The share of utilities (energy, water…) is higher; this implies that COTPROT production is more efficient with regard to the use of natural resources.

5.1.6. Sensitivity analysis

Factors which impact the most on the production cost are:

- Exchange rate. We assume that the exchange rate of 2.40 represents the highest appreciation level of Brazil Real and we consider a lower appreciation at 3.41.

- Ratio of self-financing. We test ratio from zero (investment totally funded on credit) to one (total self-financing), this hypothesis of total self-financing is realistic owing to the relative low investment cost and the high credit rate in Brazil.
- Costs of the production equipments. We consider that the costs of production equipments could fluctuate from 80% to 125% of what we determined.
- Cost of TEA. We assume that the unit cost we retain is the maximum and that it could be decreased by 30% through better identification of suppliers and better bargaining.
- Technology transfer cost. We assume that this cost could be double of the one we retained.

We think that the cost of cottonseed we obtain from a cotton producing compound is appropriate and is actually the level they want to value their product. We assume also that the unit costs of utilities are captured properly since they were provided by people yet running industrial activities.

The results of the simulations we computerized are summarized in Annex 8. Production cost could be lowered down to US$ 0.89/kg or pushed to US$ 2.71/kg. These results lead to the following important remarks:

- Less recourse to credit through self-financing is favourable to decrease production cost, this is a direct consequence of the high credit level in Brazil.
- Hence, credit rate impacts a lot. The current credit rate at 27%, if not more, while the inflation rate seems to be stable at around 7%, seems to be abusively high. Anticipation of its decrease is not unrealistic and could enhance competitiveness.
- The imprecision on the investment cost of course impacts but it comes out that its effect could be offset by the other factors, notably the credit rate or the exchange rate. An increase in the cost of the production equipment could be compensated by a depreciation of the Brazilian Real or by a decrease of the credit rate.
- Clearly, the lowest production cost (US$ 0.89/kg) is obtained when investment is totally self-financed, benefiting from a less appreciated Real (at the level experienced two years ago) and a reduction of the equipment costs. Under this situation, production cost could be close to the one of PLA in film production. This would be very attractive to potential investors to exploit the new opportunity of producing a new kind of biodegradable plastics.
- The least favourable situation pertains to conditions which are quite opposite. Under these unfavourable conditions, production cost reaches US$ 2.71 which remains somewhat competitive with regard to existing biodegradable plastics.

5.1.7. Limited competitiveness in the seed coating industry

During the implementation of the INCO Project, a 26% COTPROT solution was successfully used as raw material for filmcoating in seed industry in the Nederlands, although not full technical satisfaction was achieved. It comes out that the prospect of using COTPROT in seed coating is still impeded by no real price competitiveness and by technical limitations.

A typical commodity binder for filmcoating in the seed industry costs between €1.00 and €1.50 / kg in the Netherlands. Assuming an average price of €1.25, this is about USD 1.50. This price level pertains to the optimistic side of the production cost we estimated for COTPROT solution. In other words, we can hardly expect real price-competitiveness for COTPROT in the seed industry.

Limitations mainly come from the technical aspect. Binders used in the seed industry have a typical solids content of 50%, twice as high as the Cotprot solution. In filmcoating development the binder content is chosen on solid binder, to guarantee a certain binding capacity. The binding capacity per solids is for Cotprot definitely not higher than for a conventional commodity binder (rather somewhat lower). To achieve the required binding capacity when using COTPROT, as much as twice the amount of a conventional is needed. This naturally leads to diminish the price attractiveness of COTPROT. Even with the most favorable production cost we achieve (US$ 0.89/kg), COTPROT still turns out to be 20% more expensive than a conventional binder.

Of course additional advantages of COTPROT could help to offset its lack of price competitiveness. These advantages have yet to be elaborated.

5.2. Production cost of plastic material from extrusion of cotton seed cakes

5.2.1. Production: extension of activities within oilseed crushing plant

In the framework of the INCO Project implementation, extrusion of cottonseed proteins was experimented both through using cottonseeds and cotton seed cakes. When cottonseeds were used, kernels were ground and have to be delipidated so that the least possible of oil remained. With cotton seeds cakes, the process was simpler since the raw material is yet poor in oil content. This means that it is quite natural to consider preferably using cotton seed cakes as raw materials instead of cottonseeds. In this regard, proceeding towards extrusion from using cotton seed cakes appears to be an activity extension within a cottonseed oil plant. Of course, an existing plastics industry can also consider committing itself to prepare its own materials before further processing. For a matter of simplicity, this latter case is not being considered here although we can presume that production cost should be a little bit higher as a consequence of transportation, handling and storage of cotton seed cakes.

In Brasil and in Argentine, there are yet many oilseed crushing plants which are using cottonseeds and producing cotton seed cakes. They are potential clients for the extrusion technology whose production cost is assessed here.

5.2.2. Process inputs/outputs ratio

The implementation of the INCO project enabled to proceed to extrusion of cotton seed cakes at the laboratory level in order to clarify the processing yields at every production stage leading to the final product we call EMACOT. The outcomes of the research works conducted by Dr Laurent Ferry's team are summarized as follows:

- Grinding yield: 96% of flour from seed cakes
- Sieving yield: 45% sieved flour out of ground seed cakes
- Extrusion input/output ratio: Extruded material from cotton seed cake (EMCOT) is obtained from 73,5% of sieved flour, 18,3% of glycerol and 8,2% of water.

It is worth noting that the last experiments indicated the interest of adding PCL to replace partly seed cakes, as well as the better quality of the EMACOT by using delipidated seed kernel instead of seed cakes. Likely production costs will be a higher but not necessarily changing dramatically the positive competitiveness of the production costs we estimate here.

Extrusion was implemented through a twin-screw extruder of 100 kg/hour of capacity. We obtained information on device whose capacity is double but which remains limited from the industrial perspective. We retained optimized equipment combining four extruders which can be fed by just one grinder and one sieve. This equipment combination is the one we consider in the calculation of production costs. Of course, more information on the capacities and costs of the needed equipment by further prospecting along equipment suppliers could lead to another set of production equipment. In particular, extruder of far higher capacity should lead to economies of scale and reduce substantially production cost. This should be considered at the stage of feasibility study.

The break down of the flow movements at each production stage is shown in Annex 10 and is summarized in Table 17. The retained production equipment corresponds to an annual production capacity of 1834 tons of EMACOT, from using 3120 tons of cotton seed cakes.

Table 17. Inputs and output in producing EMACOT

Inputs		Outputs	
Products	Total amount, tons, KWh, unit	Products	Amount, tons/year
Cottonseed cakes	3 120	EMACOT	1 834
Glycerol	336		
Cans	9 169		
water	150		
electricity	355 964		

5.2.3. Equipment plan retained for cost estimation

There is no specific production equipment additional to those yet mentioned. No waste management is needed, the disposal of the solid refuses at the grinding and sieving stages should not be troublesome. Workers are associated to each production stage so that the investment in conveyers to move products from one stage to another is of limited scale.

In the area of infrastructures, investment should be limited to setting up a workshop for the processing operations since all other needed infrastructures yet exist within the oilseed crushing plant.

Since the production implements a new technology, we integrate technology transfer cost along with the provision of technical assistance. We retained the formula of having these costs being paid once for all at the launching of the production. The value we retain is only indicative.

The whole investment scheme is summarized in Annex 11. Part of the investment can be provided locally, notably in terms of infrastructures. Local investments are less sensitive to fluctuation of exchange rates. The exchange rate against US$ remains at 2.4; Imported investment accounts for more than 85% of the total (Table 18). Although there are some investments in infrastructures (buildings) but whose share in the total investment is small, we adopt a global 10-year period for depreciation as a matter of simplicity.

Table 18. Investment split-down for EMACOT

Infrastructures invest. In R$	**400 000**
Local Production equipment in R$	**222 600**
Local investment in R$	**622 600**
Local investment in US$	**259 417**
Imported Prod. equipment in $	**1 160 000**
Technology transfer, US$	**480 000**
Imported investment in US$	**1 640 000**
Total investment in US$	**1 899 417**
Depreciation in US$	**189 942**

We assume that self-financing covers 50% of the whole investment costs of US$ 1.9 millions. The remaining investment is financed through a 5-year credit. Credit is expensive in Brazil, we consider a credit rate of 2% per month which corresponds to 26.8% per year.

Material and labor costs (Table 19) are obtained along people involved in cotton and chemical industries and can be assumed to be very close to reality.

Table 19. Material and labor cost for EMACOT production

		Unit cost in R$
Cotton seed cakes	ton	280
Glycerol	ton	10 600
Cans for Cotprot (200kg)	Unit	40
water	ton	1,30
electricity	Kwh	0,23
Workers	man-month	1 200
Supervisor	man-month	3 000

5.2.4. Competitive production

Details of the cost estimation are summarized in Annex 12. Total unit cost amounts up to US$ 1.50/kg. This cost can be compared to current unit prices of competing plastics: US$ 4.92-9.84/kg for PLA, Mater-Bi or PCL. The price of these competing materials should increase owing to the price increase of crude oil.

It is noteworthy that raw material accounts for a rather small share of the production cost while glycerol represents a very big share (Table 20). This is a factor to take into consideration in the sensibility calculations. Because of the limited extruder capacity, the fix cost share is rather high. It is reasonable to expect substantial economies of scale with extruders of greater capacities.

Table 20. Production cost of EMACOT

EMACOT production (ton)	1 834	Total cost, US$	Unit cost US$/kg	Unit cost, %
Fix cost	Direct fixed capital	622 486	0,34	23%
	Labor	51 000	0,03	2%
	admin. & Overhead	50 000	0,03	2%
	Total	**723 486**	**0,39**	**26%**
Variable cost	Raw materials	364 000	0,20	13%
	Other consumables	1 634 982	0,89	59%
	Utilities	34 195	0,02	1%
	Total	**2 033 177**	**1,11**	**74%**
Total cost		**2 756 662**	**1,50**	100%

The production cost we determined appears to be lower than prices applied for existing biodegradable plastics. EMACOT production could then be profitable; the extent of this profitability depends on the pricing policy, related to commercial strategies, which goes out the scope of this analysis. Higher is the selling price, of course higher is the profit and lower is the sensitivity to constraints linked to selling the new product. This means that production capacities might be only partially used without endangering the business (concept of profitability threshold in Table 21). In other words, the risk related to the selling of a new product is reasonably low when production cost is low enough.

Table 21. Selling prices and profitability thresholds of EMACOT production

	At selling price of (US $/kg)					
	3,00	**2,80**	**2,60**	**2,40**	**2,20**	**2,00**
Profitability threshold (tons)	383	428	485	560	663	812
Ratio of capacity use	15%	16%	19%	22%	25%	31%

5.2.5. Sensitivity analysis

Factors which impact the most on the production cost are similar to the ones we identified for COTPROT production: exchange rate, ratio of self-financing, costs of the production equipments, cost of glycerol and technology transfer cost.

We think that the cost of cotton seed cake is realistic as well as the unit costs of utilities.

The results of the simulations we computerized are summarized in Annex 13. Production cost could be lowered down to US$ 0.78/kg or pushed to US$ 2.21/kg. These results lead to the same remarks underlined in the COTPROT case:

- Less recourse to credit through self-financing is favourable
- Hence, credit rate impacts a lot.
- Clearly, the lowest production cost is obtained when investment is totally self-financed, benefiting from a less appreciated Real (at the level experienced two years ago) and a reduction of the equipment costs.
- Production cost could be further lower in case higher capacity extruder can give rise to economies of scale.

5.2.6. Competitive production of PCL-EMACOT

The last experiments implemented showed that the material extrusion from cotton seed cakes gave better performance when PCL is mixed. The mixing ratio of 9/1 yet gave satisfactory results. The extrusion operation was easier to manage and the quality of the material obtained, we call PCL-EMACOT, was obviously better. The same equipment with exactly the same investment leads to a higher production of PCL-EMACOT (Table 22), from the same amount of cotton seed cakes, since more glycerol and water are needed in addition to PCL inclusion.

For the same assumptions on investment costs, raw material and consumables costs as well as functioning costs, the unit production cost of PCL-EMACOT is US$ 0.5/kg higher as compared to EMACOT (Table 23), but it is quite competitive with regard to existing biodegradable plastics materials (US$ 2.03/Kg). The same sensitivity analysis, by variation of the assumptions of the investment costs and unit costs of raw materials and consumables, but keeping the PCL cost constant, leads to unit production cost ranging from US$ 1.33 to 2.67. This variation confirms the great potential interest of PCL-EMACOT which combines cost competitiveness to rather easy technical feasibility of a technically performing material.

Table 22. Inputs and output in producing PCL-EMACOT

Inputs		Outputs	
Products	Total amount, tons, KWh, unit	Products	Amount, tons/year
Cottonseed cakes	3 120	EMACOT	2 036
Glycerol	373		
PCL	149		
Cans	10 181		
water	167		
electricity	355 964		

Table 23. Split-down of the production cost of PCL-EMACOT

EMACOT production (ton)	**2 036**	Total cost, US$	Unit cost US$/kg	Unit cost, %
Fix cost	Direct fixed capital	622 486	0,31	15%
	Labor	51 000	0,03	1%
	admin. & Overhead	50 000	0,02	1%
	Total	**723 486**	**0,36**	**18%**
Variable cost	Raw materials	364 000	0,18	9%
	Other consumables	3 005 882	1,48	73%
	Utilities	34 204	0,02	1%
	Total	**3 404 086**	**1,67**	**82%**
Total cost		**4 127 571**	**2,03**	100%

6. Conclusion

The success of new initiatives in the area of bioplastics industry asks for sustainable marketing strategy. It is reported that several failures in penetrating the general plastics market which mainly resulted from a lack of real determination of marketing strategies. Analysts observe that factors which matter in these strategies pertain to

- identifying market segments
- making products available in the targeted market segments
- making the proposed products being different and being felt different with existing ones
- determining the development rhythm
- and retaining a sound investment plan.

Market penetration will depend on critical criteria of price competitiveness, functionality and environmental effects. All these factors indeed must be addressed in a comprehensive feasibility study and which cannot be discussed in this opportunity study. The assessment of the real prospects in processing cottonseed proteins into biodegradable plastics materials still requires additional analyses.

The prospect of the demand for biodegradable plastics is nevertheless bright. This demand is clearly taking off these recent years in various parts of the world. The price increase of conventional plastics (resulting from crude oil price increase and unfavorable taxing policy) should contribute to sustain the demand for biodegradable plastics. Consequently, the anticipation of 10% for the world market share of biodegradable plastics could make sense in the next future.

It is unlikely that such a market share could be encountered in Brazil and Argentina where the level of plastics consumption is far lower than in economically developed countries. National markets can hardly be the unique outlets for the enhanced production of biodegradable plastics. Exportation must be considered; this is yet considered to be the pathway through which Brazil could improve its penetration of European and American markets.

The increasing production of cotton, particularly in Brazil, ensures high levels of availability for cottonseeds and cotton seed cakes. Cottonseeds are yet used as raw materials in oil industry. Resulting cotton seed meals are yet largely used as animal feeds. Nevertheless, there should remain enough cottonseeds and seed cakes to be used as raw materials for further processing. According to our assumptions which are, we believe, rather realistic if not pessimistic, there should be enough raw materials for nearly twenty units producing 2600 tons of COTPROT solution and far more for the production of plastics material from cotton seed cakes.

The production of COTPROT solution from cottonseeds seems to be price competitive. Fix cost is reasonable since the production derives from an activity extension within existing ginning plant. Various scenarios of investment plans have been considered, lowest price is obtained through self-financing, low price of TEA and favorable exchange rate. This price competitiveness allows considering using COTPROT solution as a substitute in manufacturing biodegradable plastics goods, like films and bags. It is nevertheless not yet sufficient to compete against conventional binding material in seed industry.

The production of plastics materials from extruding cotton seed cakes lead to a final product called EMACOT whose production cost is lower than existing biodegradable materials. Economies of scale by using extruder of higher capacity should further lower production cost and lead to higher production volume. With the extruding capacity we retain on the cost estimation, annual production by combining four extruders is inferior to 2000 tons, which is far below the amount of seed cakes available in oilseed crushing plant. Achieving real economies of scale should make the EMACOT processing further attractive to the existing cotton oil industry.

The extrusion of cotton seed proteins but mixing PCL at a 9/1 ratio leads to a material called PCL-EMACOT whose technical properties are better, whose processing is easier and with additional cost which does not alter its cost competitiveness as compared to existing biodegradable materials. The prospects of PCL-EMACOT appears quite exciting since its production was mastered at the end of the INCO Project and there still is large room for optimization.

With regard to biodegradable plastics in general, price competitiveness is nevertheless not sufficient to ensure market penetration. Products derived from using biodegradable plastics materials must comply with the expected technical requirements. This compliance must be assessed on the product-by-product basis, after identification of the products to be manufactured. It could not be addressed in the framework of this opportunity study.

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Annex 1

Summary of key indicators from LCA studies (state of the art technologies only)

Type of plastic	Functional unit	Cradle-to-gate non-renewable energy use [Mj/functional unit]	Type of waste treatment assumed for calculation of emissions	GHG Emissions [kg CO_2 eq/functional unit]	Acidification [g SO_2 eq]	Eutrophication [g PO_4 eq]
Petrochemical polymers						
HDPE	1 kg	80	Incineration	4.84	n/a	n/a
LDPE	1 kg	80.6	Incineration	5.04	n/a	n/a
LDPE	1 kg	91.7	80% Incineration + 20% landfill	5.20	17.4	1.1
Nylon 6	1 kg	120	Incineration	7.64	n/a	n/a
PET (bottle grade)	1 kg	77	Incineration	4.93	n/a	n/a
PET (general purpose)	1 kg	87	Incineration	5.98	n/a	n/a
EPS	1 kg	84	Incineration	5.88	n/a	n/a
EPS	1 kg	86	None	2.80	170	5.8
EPS (PS +2%SBR+Pentan+Butan)	1 kg	87	None	2.72	18.5	1.5
Petrochemical co-polymers						
Polycaprolactone (PCL)	1 kg	83	Incineration	3.1	5.5	0.5
Polycaprolactone (PCL)	1 kg	77	Incineration	5.0-5.7	n/a	n/a
Polyvinyl alcohol (PVOH)	1 kg	102	Incineration	2.7	8.0	0.9
Polyvinyl alcohol (PVOH)	1 kg	58	Incineration	4.1-4.3	n/a	n/a
Biodegradable Polymer Pellets						
TPS	1 kg	25.4	Incineration	1.14	n/a	n/a
TPS	1 kg	25.5	80% incin + 20% compost	1.20	10.9	4.7
TPS	1 kg	25.4	100% composting	1.14	10.6	4.7
TPS (maize starch, 5.4% maize grit, 12.7% PVOH)	1 kg	18.9	None, no credit for carbon uptake by plants	1.10	4.6	0.5
TPS + 15% PVOH	1 kg	24.9	Incineration	1.73	n/a	n/a
TPS + 52.5% PCL	1 kg	48.3	Incineration	3.36	n/a	n/a
TPS + 60% PCL	1 kg	52.3	Incineration	3.60	n/a	n/a
Mater-Bi foam grade	1 kg	32.4	Composting	0.89	20.8	2.8
Mater-Bi foam grade	1 kg	36.5	Waste water treatment plant	1.43	20.7	3.1
Mater-Bi film grade	1 kg	53.5	Composting	1.21	10.4	1.1
PLA	1 kg	57	Incineration	3.84	n/a	n/a
PHA by fermentation	1 kg	81	n/a	n/a	n/a	n/a
PHB, various processes	1 kg	66-573	n/a	n/a	n/a	n/a
Loose Fills						
Mater-Bi starch loose fills	1 m^3 (10kg)	492	Waste water treatment plant	21.0	276	39
FloPak starch fills	1 m^3 (12kg)	277	30% incin, 70% landfill	33.5	83	9.9
EPS loose fill	1 m^3 (4.5 kg)	660	Incineration	56	325	42
FloPak EPS loose fill	1 m^3 (0.4kg)	453	30% incin, 70% landfill	22.5	85	8
EPS loose fill (by recycling of PS waste)	1 m^3 (0.4kg)	361	30% incin, 70% landfill	18.6	107	9.9
Films and Bags						
TPS film	100 m^2, 150 µm	649	80% incin, 20% landfill	25.3	239	103
Mater-Bi starch film	100 m^2, 20 µm	133	Composting	2.98	26.5	2.8
PE film	150 m^2, 150 µm	1340	80% incin, 20% landfill	66.7	238	15

Source: Patel 2002

Source : Holdings 2004

Annex 2

Summary of Material sources for Biodegradable Plastics and Applications

No	Source	Material	Comments	Special Properties	Applications
1	Hemp	Cellulose, maybe seed.	Easy to cultivate. Will encourage bioregional economics.	Higher strength to weight ratio. Agronomic benefits for the soil in rotations.	Any type of plastic particularly car parts.
2	Elephant Grass *Miscanthus*	Cellulose	Environmentally-friendly crop, high yields, high energy efficiency	Adds strength to composites, without increasing costs	Useful as a filler in biocomposites, particular use in car parts
3	Other Natural Fibres	Cellulose	Vast range of sources – jute, sisal & more Advantages are cost, availability, recyclability, energy use	Low density, high stiffness are the properties contributed to biocomposites	Thermoplastic biocomposites Use in headliners, door panels, package trays, rear shelves, and other interior features
4	Wheat	(i) Straw (ii) Gluten (iii) Starch	Natural, abundant, can be easily isolated, relatively low cost	(i) Consistent, reproducible, high quality plastic (ii) Unusual solubility adhesive properties	Films, Resins, Polymers
5	Soybean	Proteins	When degraded act like soil conditioner.	Films can block UV rays.	Water-repellent biodegradable plastic wrap for grocery bags, lawn and trash bags, and agricultural mulch film extruded-foam products like plates, fast-food "clam shell" containers and construction materials, and in injection-moulded products like utensils and golf tees
6	Maize	(i) Zein (ii) Cornstarch (ii) PLA (iv) Gluten meal (v) Protein	High cost of zein is the negative factor. Corn Gluten Meal is co-product of ethanol production	Zein produces tough, flexible, shatter resistant, and low water permeation products. Corn protein has low material cost and fabricability Starch is being used as an effective biopolymer	Zein can be used as wraps, films and packaging, mulching films, covers for hay bales, loose fill packaging Corn-based PLA gives Compostable plastics, packaging films, fast food serving utensils, moulded foam packaging etc. Corn proteins can be used for food trays, because of

Annex 2 stnd **Summary of Material sources for Biodegradable Plastics and Applications**

No	Source	Material	Comments	Special Properties	Applications
7	Lignocellulosic wastes at paper mills	Hemicellulose-lignin	60 million tonnes available annually worldwide after cellulose extraction	Durability & water resistance. Substitute for phenol in phenol formaldehyde	Shaped into various parts via injection moulding, vehicle interiors.
8	Cassava	Starch	Fourth most important starch crop.	Low cost production, also external benefits	Biodegradable plastics are one of the many uses of cassava starch.
9	Potato	Starch	Third most important starch crop.	Large quantities of primary and waste product available at low cost	Food containers like trays, cups, plates, wraps etc. are produced from potato starch
10	Other oilseeds	Vegetable oils	Ample palm oil availability in Malaysia. Ample canola elsewhere	Effective PHB substrates	Mulch films
11	Sorghum	Starch	Low cost	C4 Photosynthesis	Various biodegradables
12	Sugar cane	Sugar	Low cost	Substrate for PHA & PLA	Biodegradable plastics

Annex 3

Comparative Summary account of Different material sources for Biodegradable Plastics:

No.	Biomaterial Source	Attributes	Constraints
1	Starch-based	Natural, abundant, can be easily isolated, relatively low cost. Consistent, reproducible, high quality plastics possible. Suitable for short-life prod.- food containers, food packaging.S tarch from corn, cassava, rice, potato etc. have different properties	Hydrophilicity can be a problem (solved with polycaprolactone blend), as well as tensile strength.
2	Lignin-based	Abundant. Shaped into various parts via injection moulding Useful for niche products like degradable packaging, plant pots, golf-tees or fireworks casings, car interiors, car door panels etc.	Limited applications, expensive, though growing interest as a replacement for reinforcing fibre material in composite structures.
3	Cellulose-based	Hydrophilic but derivatives, which are hydrophobic can be prepared. High strength, water resistance, total degradability & low cost.	Cellophane not thermoplastic, problems with heat-sealed. Costs of separating from lignin and hemicellulose,
4	Protein-based	Suitable in composites, Soybean protein films can block UV rays, extrudable, injection mouldable, suitable for water-repellent biodegradable plastic wrap for grocery bags, lawn and trash bags, and agricultural mulch film. Produces tough, flexible, shatter resistant & low water permeable products. Suitable for mulch films, hay bales. Corn protein has low material cost and fabricability.	Cost of soy-based plastics is a little higher than conventional plastics, not suitable for durable items.
5	Agro-fiber-based	Low cost, low density, high stiffness & suitable for composites, potentially outstanding reinforcing fillers in thermoplastic composites.	Range of applications not enough for replacement of existing materials.
6	Chitin/Chitosan	Chitosan forms films, produces materials with high gas barrier, good for coatings, interesting for food packaging due to antimicrobial properties. Better properties with cellulose and starch as composites.	Limited applications. Plenty available but cost of gathering could be high.
7	Chicken feathers	Use for films, sheets, wrappers, can-holders. Composite moulded into automobile dashboards & door panels.	Processing of feathers tedious, Limited potential.

Source: Holdings, 2004

Annex 3, ctnd

No.	Biomaterial Source	Attributes	Constraints
8	PHA/PHB	Hydrolyzable, fully biodegradable. Properties similar to PP. Produce thin wall, complex structures. Small machines possible, fast cycle times (Hanggi 2001). Overcome brittleness with nucleants. Cost coming down.	Either stiff or brittle, poor solvent resistance, high cost (today), limited applications. Low viscosity melt. Difficult to extrude or inject.
9	PLA-based	Properties close to existing polymers, ease of processing, suitable packaging material, sustained release system, biocompatible enables medical use.	Costs are still higher than conventional polymers, but coming down.
10	Polycaprolactone: Biodegradable synthetic	Hydrolyzable; low softening and melting points; compostable; suitable for long-life & controlled life products & blends to modify other polymers.	Long time to degrade & may reduce the environmental impact. Questions remain about accumulations in soil.
11	PVA :Biodegradable. synthetic	Water soluble; dissolves in composting, packaging & bagging applications	Hydrophilic
12	Polyglycolic acid: Biodegrad synthetic	Used in a variety of pharmaceutical & biomedical applications & implants	Cost. Low volume speciality applications.
13	Polyethylene oxide: Biodeg. synthetic	Water soluble thermoplastic, used in adhesives and paper coatings	Cost. Low volume speciality applications
14	Palm oil	Amplé in Malaysia, can be used for PHB/V production	Not economical outside Malaysia
15	Genetically engineered crops	Reduce costs of PHB/V production to competitive level. PHA production in corn stover/stubble is promising when energy efficiency is improved.	Technical capability incomplete, low volume, market response to use of GMOs.

Major Biodegradable Materials Producers

COMPANY	BASE POLYMER	FEEDSTOCK	COST, $/lb	CAPACITY, MM LBNR
Cargill, Minneapolis, MN	Polylactide (PLA)	Renewable Resources, Corn	1.00 -3.00	Pilot scale ('94 scaleup)
Ecochem, Wilmington, DE	Polylactide copolymers	Renewable Resources, Cheese whey, corn	< 2.00 proj'd	0.15 ('94 scaleup)
Flexel, Atlanta **GA**	Cellophane (Regenerated cellulose	Renewable resources	**2.15**	100
Zeneca (business unit of ICI)	Poly(hydroxybutyrate-co-hydroxyvalerate), PHBV	Renewable resources -- carbohydrates (glucose), organic acids	8.00 - 10.00; 4.00 proj'd	0.66, additional capacity slated for '96 is 11 - 22
Novamont/Ferruzzi-Montedison, New York, NY, & Italv	Starch-synthetic polymer blend containing approx. 60% starch	Renewable resources + petrochemical	1.60 - 2.50	50, in Turni, Italy
Novon Products (Warner-Lambert Div.), Morris Plains, NJ	Thermoplastic starch polymer compounded with 5-25% additives	Renewable resources, Starch	2.00 - 3.00	100
Union Carbide, Danbury, CT	Polycaprolactone (Tone polymer)	Petrochemical	2.7	< 10
Air Products & Chemicals, Allentown. PA	Polyvinyl alcohol (PVOH) & Thermoplastic PVOH alloys (VINEX)	Petrochemical	1.0 -1.25 (PVOH); 2.50-3.00 (VINEX)	150 - 200 (water sol. PVOH); 5 (VINEX)
National Starch & Chemical, Bridgewater, NJ	Low ds starch ester	Renewable resources, Starch	2.00 - 3.00	Not available
Planet Packaging Technologies, San Diego, CA	Polyethylene oxide blends (Enviroplastic) .	Petrochemical	**3**	10

R. Narayan, 1993

Annex 5: Inputs and outputs at the various stages of the COTPROT production

Operations	**Seed dehusking**		**Dehusking yield**	**50,00%**
Material	Amount kg/hour or unit/hr	Total amount, tons, KWh, unit		
Cottonseeds	5 290	**7 406**		
Seed kernels	2 645	3 703		
Energy KWh	15	**21 000**		
Workers	2	**2 800**		

Operations	**Kernel grinding & sieving**		**Grinding & sieving yield**	**64,00%**
Material	Amount kg/hour or unit/hr	Total amount, tons, KWh, unit		
Seed kernels	2 645	3 703		
Flour	1 693	2 370		
Energy KWh	28	**39 517**		
Workers	2	**2 800**		

Operations	**Flour dispersion**		**Dispersion yield**	**476,49%**
Material	Amount kg/hour	Total amount, tons, KWh, unit		
Flour	1 693	2 370		
Water	6 078	**8 509**		
TEA	296	**414**		
Steam	479	**670**		
Flour dispersion	8 066	11 292		
Energy KWh	12	**16 800**		
Workers	2	**2 800**		

Operations	**Solid separation**		**Separation yield**	**60,56%**
Material	Amount kg/hour	Total amount, tons, KWh, unit		
Flour dispersion	8 066	11 292		
Solids residues	3 178	**4 449**		
Dispersion	4 885			
Energy KWh	59	**82 811**		
Workers	1	**1 400**		

Operations	**Centrifuging**		**Centrifuge yield**	**86,00%**
Material	Amount kg/hour	Total amount, tons, KWh, unit		
Dispersion	4 885	6 839		
Solids residues	31	**43**		
Foam	704	**986**		
Cotprot 11° Brix	4 200	5 880		
Energy KWh	2	**3 420**		
Workers	1	**1 400**		

Operations	**Evaporation**		**Evaporation yield**	**86,00%**
Material	Amount kg, KWh, unit/hour	Total amount, tons, KWh, unit		
Dispersion	4 200	5 880		
Water	2 339	**3 275**		
Steam	1 439	**2 015**		
Cotprot 26° Brix	1 859	**2 602**		
Energy KWh	54	**75 309**		
Cans (200 kg)	10	**14 000**		
Workers	5	**7 000**		

Annex 6: Investment cost in producing COTPROT

Item group	Item	Number of units	Unit cost in currencies		Unit cost in US $			Total cost in US $			Depreciation	Depreciation
			Import ($)	Local	Import	Local	Total	Import	Local	Total	duration	US $/year
Land	Land purchase	0		0		0	0	0	0	0	30	
	Land acquisition Taxes	0		0		0	0	0	0	0	30	
Transportation	roads	0		0		0	0	0	0	0	30	
	cars & lorries	0		0		0	0	0	0	0	5	
Water supply	Water supply network	0		0		0	0	0	0	0	15	
Steam supply	Steam production equipment	0		0		0	0	0	0	0	15	
	Steam supply network	0		0		0	0	0	0	0	15	
Energy	Generator	0		0		0	0	0	0	0	10	
	Energy supply network	0		0		0	0	0	0	0	20	
Effluent and residues treatment	Aerobic or anaerobic effluent basins	1		400 000		166 667	166 667	0	166 667	166 667	10	16 667
Factory buildings	Manufacturing workshops	1		400 000		166 667	166 667	0	166 667	166 667	10	16 667
Administration	Administrative offices	0		0		0	0	0	0	0	20	
	Offices equipment & communication	0		0		0	0	0	0	0	10	
Production equipment	Seed de-huskers	1		0	1 500 000	0	1 500 000	1 500 000	0	1 500 000	10	150 000
	Kernel grinders	3		2 600		1 083	1 083	0	3 250	3 250	10	325
	Vibrating sieve	2		20 000		8 333	8 333	0	16 667	16 667	10	1 667
	Dispersion tank	12		22 000		9 167	9 167	0	110 000	110 000	10	11 000
	Solid separator	1	350 000		350 000	0	350 000	350 000	0	350 000	10	35 000
	Bowl centrifuge	2	45 000		45 000	0	45 000	90 000	0	90 000	10	9 000
	Evaporators	2	330 000		330 000	0	330 000	660 000	0	660 000	10	66 000
	Conveyers & tubes	1		400 000		166 667	166 667	0	166 667	166 667	10	16 667
	Total							**2 600 000**	**629 917**	**3 229 917**		
Technology transfer	Technology fee	1			1 000 000	0	1 000 000	1 000 000	0	1 000 000	10	100 000
	Assistance & training	1			200 000	0	200 000	200 000	0	200 000	10	20 000
Total								**3 800 000**	**629 917**	**4 429 917**		**442 992**

Infrastructures invest. In R$	**400 000**
Local Production equipment in R$	**1 111 800**
Local investment in R$	**1 511 800**
Local investment in US$	**629 917**
Imported Prod. equipment in $	**2 600 000**
Technology transfer	**1 200 000**
Imported investment in US$	**3 800 000**
Total investment in US$	**4 429 917**
Depreciation in US$	**442 992**

Total investment	4 429 917
Self financing ratio	0%
Credit amount	4 429 917
Credit duration (year)	5
Credit rate per year	27%
Remboursement annuel	-1 709 233

Annex 7: Estimation of COTPROT production cost

Cost groups	Cost sub-groups	Item groups	Item	Amount	Unit	Unit cost in currencies/unit		Unit cost in US $/unit			Total cost in US $			Total unit cost in US $/kg
						Import	Local	Import	Local	Total	Import	Local	Total	
Manufacturing costs	Materials	Raw materials	Cottonseed	7 406	ton		280		116,67			864 033	864 033	0,33
		Processed materials	TEA	414	ton		9960		4150,00			1 718 343	1 718 343	0,66
		Packaging	Cans for Cotprot (20kg)	14 000	Unit		40		16,67			233 333	233 333	0,09
		Public services	water	8 509	ton		1,3		0,54			4 609	4 609	0,00
			steam	2 685	ton		100		41,67			111 887	111 887	0,04
			electricity	238 857	Kwh		0,23		0,10			22 890	22 890	0,01
	Labor	Workshop labor	Workers	91	man-month		1200		500,00			45 500	45 500	0,02
			Supervisor	8,0	man-month		3000		1250,00			10 000	10 000	0,00
	General workshop costs	Infrastructures maintenance											16 000	0,01
		Equipment maintenance											122 530	0,05
	Total manuf. Costs												**3 149 125**	**1,21**
Exploitation costs	Overhead costs											10 000	10 000	0,00
	Sale and distribution costs											40 000	40 000	0,02
	Total exploitation costs												**3 199 125**	**1,23**
Production costs	Financial costs											854 616	854 616	0,33
	Depreciation and amortization												442 992	0,17
	Total production costs												**4 496 733**	**1,73**

Reminder on main assumptions

R$ vs US$	2,4	Total invest US$	4 429 917	cot_seed R$	280	steam R$/ton	100	Workers R$/month	1200,00
credit rate	27%	Self financing	50%	water R$/ton	1,30	electricity R$/KWh	0,23	Supervisor R$/month	3000,00

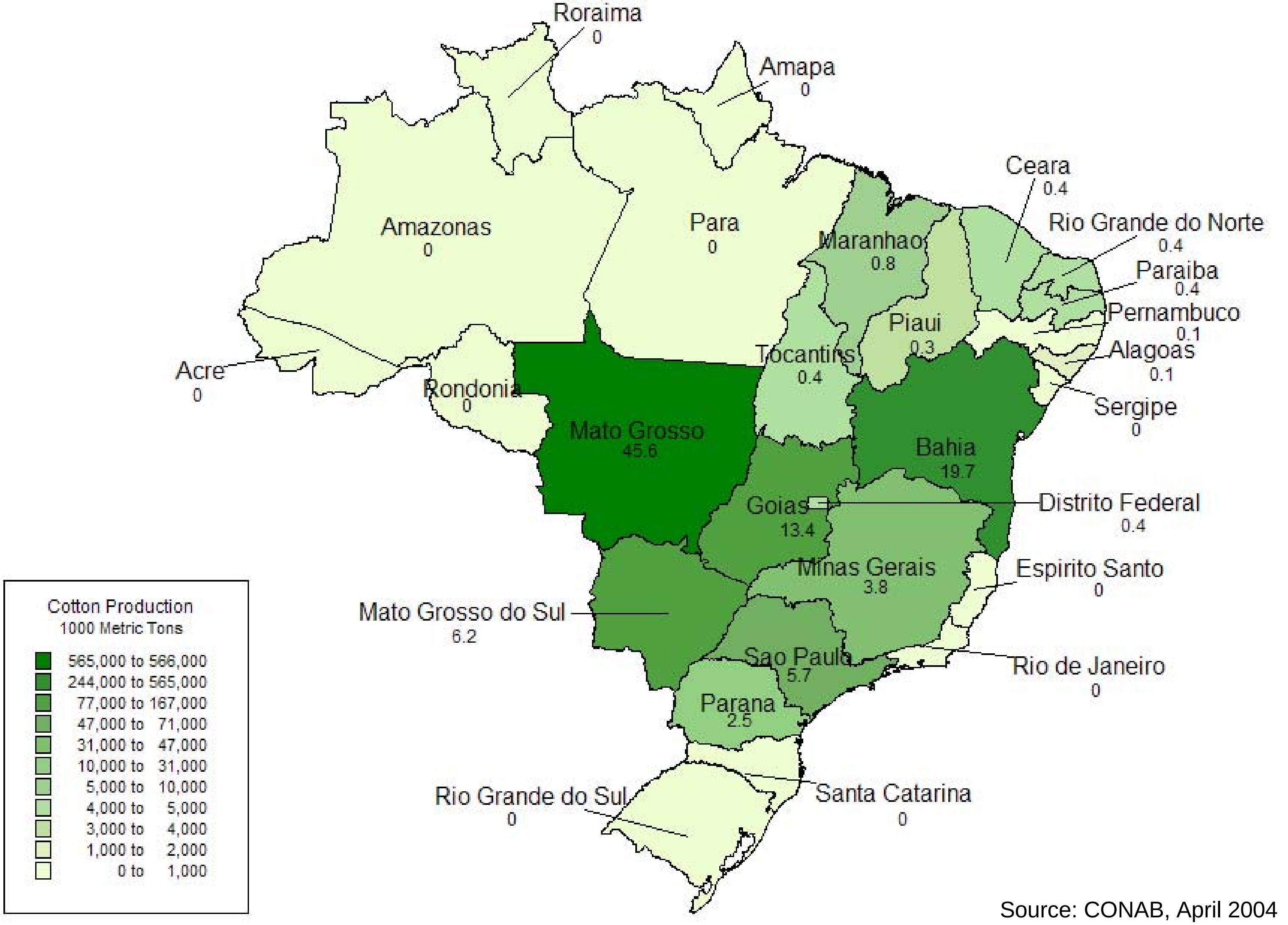
Annex 8: Sensitivity calculations of COTPROT production costs

	Hypo_H1	Hypo_H2	Hypo_H3	Hypo_H4	Hypo_H5	Hypo_H6	Hypo_H7	Hypo_H8	Hypo_H9	Hypo_H10
Self financing	**50%**	**50%**	**50%**	**75%**	**100%**	**100%**	**0%**	**100%**	**0%**	**0%**
Exch. Rate	**2,40**	**2,40**	**2,88**	**2,88**	**3,41**	**2,40**	**2,40**	**3,41**	**3,41**	**2,40**
credit rate	**27%**	**27%**	**32%**	**27%**	**27%**	**27%**	**40%**	**21%**	**21%**	**27%**
Total invest US$	**4 429 917**	**4 429 917**	**5 394 875**	**4 555 900**	**4 694 482**	**4 429 917**	**6 437 396**	**3 995 585**	**4 694 482**	**5 237 396**
cot_seed R$/ton	280	280	280	280	280	280	280	280	280	280
water R$/ton	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30
steam R$/ton	100	100	100	100	100	100	100	100	100	100
electricity R$/KWh	0	0	0	0	0	0	0	0	0	0
Workers R$/month	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00
Supervisor R$/month	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00
Unit Production total cost US$/kg	**1,73**	**1,53**	**1,54**	**1,22**	**0,93**	**1,40**	**2,71**	**0,89**	**1,55**	**2,22**
Unit Prod. Fix cost, US$/kg	**0,59**	**0,59**	**0,76**	**0,44**	**0,27**	**0,26**	**1,58**	**0,23**	**0,89**	**1,09**
Unit Prod. variable cost, US$/kg	**1,14**	**0,94**	**0,78**	**0,78**	**0,66**	**1,14**	**1,14**	**0,66**	**0,66**	**1,14**
Profitability threshold (tons of Cotprot 26°Brix) at selling price of 2,00 US$/kg	1 784	1 451	1 615	930	526	795	4 742	452	1 736	3 267
Profitability threshold, price of 2,40 US$/kg	1 219	1 054	1 216	700	405	543	3 241	348	1 337	2 233
Profitability threshold, price of 2,80 US$/kg	926	828	975	562	329	413	2 462	283	1 087	1 696

Details of the simulation assumptions

	Hypo_H1	Hypo_H2	Hypo_H3	Hypo_H4	Hypo_H5	Hypo_H6	Hypo_H7	Hypo_H8	Hypo_H9	Hypo_H10
Exchange rate vs US $	2,40	2,40	2,88	2,88	3,41	2,40	2,40	3,41	3,41	2,40
Exchange rate vs €	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
Working hours	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Local equipment R$	1 511 800	1 511 800	1 889 750	1 511 800	1 511 800	1 511 800	1 889 750	1 209 440	1 511 800	1 889 750
Imported Prod. equipment, US$	2 600 000	2 600 000	3 250 000	2 600 000	2 600 000	2 600 000	3 250 000	2 080 000	2 600 000	3 250 000
Self-financing	50%	50%	50%	75%	100%	100%	0%	100%	0%	0%
Technology transfer, $US	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	2 000 000	1 000 000	1 000 000	1 000 000
Assistance & training, US$	200 000	200 000	200 000	200 000	200 000	200 000	200 000	200 000	200 000	200 000
credit rate, per year	27%	27%	32%	27%	27%	27%	40%	21%	21%	27%
Cottonseed, R$/ton	280	280	280	280	280	280	280	280	280	280
TEA, R$/ton	9 960	6 972	6 972	6 972	6 972	9 960	9 960	6 972	6 972	9 960
Cans for 200 kg Cotprot, R$/unit	40	40	40	40	40	40	40	40	40	40
water, R$/ton	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30
steam, R$/ton	100	100	100	100	100	100	100	100	100	100
electricity, R$/KWh	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23
Workers, R$/month	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Supervisor, R£/month	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Overhead costs, US$/year	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Sale and distribution costs, US$/year	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000

Brazil Cotton Production Estimates – April 2004



Source: CONAB, April 2004

* Each state's share of production is shown under the state's name.

Annex 10: Input/output at each stage of EMACOT production

Operations	**Cake grinding**		**Grinding yield**	**96,00%**
Material	Amount kg/hour or unit	Total amount, tons, KWh, hours, unit		
Cotton seed cakes	1 300	**3 120**		
Cake flour	1 248	2 995		
Energy KWh	15	**36 000**		
Workers	2	**4 800**		

Operations	**Sieving**		**Sieving yield**	**45,00%**
Material	Amount kg/hour or unit	Total amount, tons, KWh, unit		
Cake flour	1 248	2 995		
Sieved flour	562	1 348		
Energy KWh	13	**31 964**		
Workers	2	**4 800**		

Operations	**Plastification within Twin-screw extruder**		**Plastification yield**	**136,05%**
Material	Amount kg/hour	Total amount, tons, KWh, unit		
Sieved flour	562	1 348		
Water	63	**150**		
Glycerol	140	**336**		
EMACOT	764	1 834		
Energy KWh	120	**288 000**		
Workers	2	**4 800**		

Annex 11: Investment cost to manufacture EMACOT

Item group	Item	Number of units	Unit cost in currencies		Unit cost in US $			Total cost in US $			Depreciation	Depreciation
			Import ($)	Local	Import	Local	Total	Import	Local	Total	duration	US $/year
Production equipment	Grinders	1		2 600		1 083	1 083	0	1 083	1 083	10	108
	Vibrating sieve	1		20 000		8 333	8 333	0	8 333	8 333	10	833
	Twin-screw extruder	4			270 000		270 000	1 080 000	0	1 080 000	10	108 000
	Peristaltic pump	4			20 000		20 000	80 000	0	80 000	10	8 000
	Conveyers & tubes	1		200 000		83 333	83 333		83 333	83 333	10	8 333
	Sub-Total							**1 160 000**	**92 750**	**1 252 750**		**125 275**
Infrastructures	Manufacturing workshop	1		400 000		166 667	166 667		166 667	166 667	10	16 667
	Sub-Total							**0**	**166 667**	**166 667**		**16 667**
Technology transfer	Technology fee	1			400 000		400 000	400 000	0	400 000	10	40 000
	Assistance & training	1			80 000		80 000	80 000	0	80 000	10	8 000
	Sub-Total							**480 000**	**0**	**480 000**		**48 000**
	Total							**1 640 000**	**259 417**	**1 899 417**		**189 942**

Infrastructures invest. In R$	**400 000**
Local Production equipment in R$	**222 600**
Local investment in R$	**622 600**
Local investment in US$	**259 417**
Imported Prod. equipment in $	**1 160 000**
Technology transfer, US$	**480 000**
Imported investment in US$	**1 640 000**
Total investment in US$	**1 899 417**
Depreciation in US$	**189 942**

Total investment	1 899 417
Self financing ratio	50%
Credit amount	949 708
Credit duration (year)	5
Credit rate per year	27%
Remboursement annuel	-366 434

Annex 12: Details of the EMACOT production cost estimation

Cost groups	Cost sub-groups	Item groups	Item	Amount	Unit	Unit cost in currencies/unit		Unit cost in US $/unit			Total cost in US $			Total unit cost in US $/kg
						Import	Local	Import	Local	Total	Import	Local	Total	
Manufacturing costs	Materials	Raw materials	Cotton seed cakes	3 120	ton		280		116,67			364 000	364 000	0,20
		Processed materials	Glycerol	336	ton		10600		4416,67			1 482 166	1 482 166	0,81
		Packaging	Cans for 200 kg	9 169	Unit		40		16,67			152 816	152 816	0,08
		Public services	water	150	ton		1,3		0,54			81	81	0,00
			electricity	355 964	Kwh		0,23		0,10			34 113	34 113	0,02
	Labor	Workshop labor	Workers	72	man-month		1200		500,00			36 000	36 000	0,02
			Supervisor	12,0	man-month		3000		1250,00			15 000	15 000	0,01
	General workshop costs	Infrastructures maintenance											16 000	0,01
		Equipment maintenance											50 110	0,03
	Total manuf. Costs												**2 150 287**	**1,17**
Exploitation costs	Overhead costs											10 000	10 000	0,01
	Sale and distribution costs											40 000	40 000	0,02
	Total exploitation costs												**2 200 287**	**1,20**
Production costs	Financial costs											366 434	366 434	0,20
	Depreciation and amortization												189 942	0,10
	Total production costs												**2 756 662**	**1,50**

Reminder on main assumptions

R$ vs US$	2,40	Total invest US$	1 899 417	seed cake R$	280			Workers R$/month	1200,00
credit rate	27%	Self financing	50%	water R$/ton	1,30	electricity R$/KWh	0,23	Supervisor R$/month	3000,00

Annex 13: Sensitivity calculations of the EMACOT production cost

	Hypo_H1	Hypo_H2	Hypo_H3	Hypo_H4	Hypo_H5	Hypo_H6	Hypo_H7	Hypo_H8	Hypo_H9	Hypo_H10
Self financing	**50%**	**50%**	**50%**	**75%**	**100%**	**100%**	**0%**	**100%**	**0%**	**0%**
Exch. Rate	**2,40**	**2,40**	**2,88**	**2,88**	**3,41**	**2,40**	**2,16**	**3,41**	**3,41**	**2,40**
credit rate	**27%**	**27%**	**32%**	**27%**	**27%**	**27%**	**40%**	**21%**	**21%**	**27%**
Total invest US$	**1 899 417**	**1 899 417**	**2 319 125**	**1 951 300**	**2 008 372**	**1 899 417**	**2 701 844**	**1 702 697**	**2 008 372**	**2 254 271**
seed cake R$/ton	280	280	280	280	280	280	280	280	280	280
water R$/ton	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30
Glycerol, R$/ton	10 600	7 420	7 420	7 420	7 420	10 600	10 600	7 420	7 420	10 600
electricity R$/KWh	0	0	0	0	0	0	0	0	0	0
Workers R$/month	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00	1200,00
Supervisor R$/month	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00	3000,00
Unit Production total cost US$/kg	**1,50**	**1,26**	**1,21**	**1,02**	**0,80**	**1,30**	**2,21**	**0,78**	**1,18**	**1,81**
Unit Prod. Fix cost, US$/kg	**0,39**	**0,39**	**0,49**	**0,30**	**0,19**	**0,19**	**0,98**	**0,17**	**0,57**	**0,70**
Unit Prod. variable cost, US$/kg	**1,11**	**0,87**	**0,72**	**0,72**	**0,61**	**1,11**	**1,23**	**0,61**	**0,61**	**1,11**
Profitability threshold (tons of Cotprot 26°Brix) at selling price of 2,00 US$/kg	812	638	707	425	255	401	2 333	223	754	1 435
Profitability threshold, price of 2,40 US$/kg	560	472	539	323	198	277	1 534	173	585	990
Profitability threshold, price of 2,80 US$/kg	428	374	435	261	162	211	1 143	142	478	756

Details of the simulation assumptions

	Hypo_H1	Hypo_H2	Hypo_H3	Hypo_H4	Hypo_H5	Hypo_H6	Hypo_H7	Hypo_H8	Hypo_H9	Hypo_H10
Exchange rate vs US $	2,40	2,40	2,88	2,88	3,41	2,40	2,16	3,41	3,41	2,40
Exchange rate vs €	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
Working hours	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400
Local equipment R$	622 600	622 600	622 600	622 600	622 600	622 600	622 600	622 600	622 600	622 600
Imported Prod. equipment, US$	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000	1 160 000
Self-financing	0,50	0,50	0,50	0,75	1,00	1,00	0,00	1,00	0,00	0,00
Technology transfer, $US	400 000	400 000	400 000	400 000	400 000	400 000	400 000	400 000	400 000	400 000
Assistance & training, US$	80 000	80 000	80 000	80 000	80 000	80 000	80 000	80 000	80 000	80 000
credit rate, per year	0,27	0,27	0,32	0,27	0,27	0,27	0,40	0,21	0,21	0,27
Seed cake, R$/ton	280	280	280	280	280	280	280	280	280	280
Glycerol, R$/ton	10 600	7 420	7 420	7 420	7 420	10 600	10 600	7 420	7 420	10 600
Cans for 200 kg Cotprot, R$/unit	40	40	40	40	40	40	40	40	40	40
water, R$/ton	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,30
steam, R$/ton	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity, R$/KWh	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23
Workers, R$/month	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Supervisor, R£/month	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Overhead costs, US$/year	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Sale and distribution costs, US$/year	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000	40 000