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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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APPROPRIATE TECHNOLOGY FOR THE PRODUCTION OF SUGAR

TECHNOLOGICAL CHOICES IN SUGAR PROCESSING
Background Paper

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TECHNOLOGICAL CHOICES IN SUGAR PROCESSING

by

Intermediate Technology Development Group Ltd (ITDG)*
United Kingdom

* This paper was prepared by G. B. Hagelberg and E. W. Krause on behalf of ITDG.

1. Introduction and summary

Sugar manufacturing has come to play an important role in feeding the world's population. Globally, per capita sugar consumption now exceeds 20 kilograms per year, equivalent to about five level table spoons per day. Directly or in processed food, sugar furnishes as a rule about one-seventh of the human energy intake in medium and highly developed countries.

In its barest essentials, sugar processing consists of a series of liquid-solid separations to isolate the sucrose formed by photosynthesis in living plants. Four basic processes are involved: juice extraction, purification, evaporation, and crystallization. These fundamental steps are at present carried out by various methods and over a spectrum of scales extending from tiny peasant-operated, animal-powered cottage enterprises to gigantic, highly automated factories. Different types of sugar are made, but most product characteristics admit a choice of operating procedures and are not uniquely determined by the size, design and complexity of the equipment used. Characteristic of sugar manufacturing is a technological pluralism that reflects the great age and wide geographical distribution of the industry.

The origins of the sugar industry are lost in prehistory. Sugar manufacturing probably began on the Indian subcontinent. Tropical Asia harbours several species of palms which when tapped yield a juice that is either fermented or boiled down to sugar. Sugar cane has been grown for thousands of years as a garden plant for chewing. By the fourth century B.C., cane was being cultivated in India to make sugar. It is possible that the Indians also had some knowledge of refining, but the earliest firm evidence of the remelting and recrystallization of raw sugar comes from Persia around 600 A.D. The Arabs spread the cultivation and processing of sugar cane westward around the Mediterranean. From Spain, the industry moved to Madeira and thence to the Canary Islands, the Azores and West Africa in the fifteenth century. The starting point of the sugar industry in the Western Hemisphere dates from 1493, when Columbus took seed cane and expert cultivators from Gomera in the Canaries on his second voyage to Hispaniola (Deerr 1949-50).

By contrast, the manufacture of sugar from beet is the result of relatively recent scientific effort. Although used as a vegetable and in medicine since ancient times, beets did not become a commercial source of sugar until the beginning of the nineteenth century, following the discovery by the German chemist Marggraf some fifty years earlier that the roots contained a substance identical with cane sugar. The first European beet sugar factory was established around 1800, the first American plant in 1838. Timoshenko and Swerling (1957) remarked that the development of the beet sugar industry in the nineteenth century provided the earliest example of the market for an important tropical product being seriously eroded by the application of modern scientific methods in relatively advanced countries.

Sugar cane, a giant grass related to maize and sorghum, is cultivated in the tropical and subtropical regions of the world. Sugar beet, a member of the Goosefoot family, grows best in cooler latitudes, but adapts itself to many climatic conditions, and in North America is grown in Arizona and the Imperial Valley of California as well as in the Canadian provinces of Alberta, Manitoba and Quebec. The fact that a product practically identical in its refined state is obtainable from two altogether dissimilar plants has made possible the global dispersion of the industry.

According to FAO figures, about 22 million hectares of beet and cane -- roughly the area of England, Scotland and Wales -- were harvested in 1976, by far the greater part for processing into sugar, with cane accounting for just under 60% of the total acreage harvested. Sugar is produced in over 100 countries. Industries are located in countries at every contemporary stage of economic development, of every size and population, some producing only for domestic consumption, others primarily for export, with annual national outputs ranging from less than 10,000 to more than 10 million tonnes of sugar of various types. World production amounted to about 98.5 million tonnes in 1976, nearly 60% of it in developing countries.

The present era of the sugar industry began in the 1880s, by which time the essential elements of modern sugar manufacturing -- multiple-mill extraction, diffusion,clarification procedures using lime, carbon dioxide or sulphur dioxide, vacuum boiling, and centrifuging -- were known, if not understood. But although henceforth predominant, these new techniques did not altogether supplant earlier practices. The process of technological differentiatic initiated at the close of the eighteenth century by the introduction of steam drive in sugar cane milling left the industry a hundred years later broadly divided into two distinct sectors, as significant quantities of sugar continued to be produced by small operators using traditional methods. The survival of earlier practices in various parts of the world has largely contributed to the present diversity of the state of the art in sugar manufacturing and makes this a particularly fertile field for the study of appropriate technologies.

Until fairly recently, the demarcation line between the two sectors was based on the use of centrifugal machines, and sugars were classified into 'centrifugal' and 'noncentrifugal', it being understood that the latter were produced by small-scale processors employing artisan methods. With the introduction of small hand-operated or motor-powered centrifugals in artisan enterprises beginning about fifty years ago, small-scale and noncentrifugal ceased to be synonymous. Although experts now tend to distinguish between modes of sugar production not by the method of finishing but by whether the juice is boiled in open pans or under vacuum, the terms 'centrifugal' and 'noncentrifugal' survive with diverse interpretations in international sugar statistics. Other technological developments in the artisan sector and the increasing size of some open-pan installations have further undermined dualist conceptions of the sugar industry and created additional problems of classification. Incomplete estimates published by FAO put world production of noncentrifugal sugar at 12.1 million tonnes in 1976, including about 1 million tonnes of centrifugal sugar produced in India by open-pan boiling; the centrifugal sugaroutput of vacuum-pan factories was reported to be 86.4 million tonnes.

For the last hundred years, research and development in the sugar industry has been mainly concerned with refinements of the basic processes and innovations in machinery and equipment, particularly the transition from batch to continuous operations, the introduction of measuring instruments and computeri ed process control systems, and the automation of various phases. The aims have been to improve product quality, eliminate losses, increase throughput, and reduce labour requirements.

Existing sugar factories still differ widely in size, although economies of scale have sustained a secular trend toward ever larger installations. Guided by the relative availability of the factors of production in industrialized countries, mainstream Western processing technology has developed in the direction of substituting capital for labour. Manpower requirements have been steadily reduced, but at an increasing capital cost. The gains in technical efficiency of large-scale, capital-intensive sugar factories are impressive. The gains in economic efficiency are more difficult to establish, and there is reason to believe that it has not been possible to reduce both capital and labour costs per unit of output.

Economies of scale work in certain ways. Size most strongly affects labour costs, since the number of operating and administrative personnel grows more slowly than other inputs as processing capacity expands. Far less incisive is the effect of traditional engineering rules of thumb based on the notion that, other things being equal, capital costs tend to increase in proportion to the surface area of the materials used, whereas processing capacity rises in proportion to volume. This is relevant to sugar processing as long as most of the capital cost is made up of buildings, containers and other equipment enlargeable without duplication, rather than complex, intricately constructed machines. Not to be overlooked, however, is the stipulation that other things remain equal, which does not cover the replacement of manually operated by motor-driven devices, fulfilling the same function but of radically different design, nor the addition of measuring instruments, servomotors and other process control apparatus to the basic equipment. These may amount to a change of technology, using that term in the wider sense of a system of production in which there exists a strong interdependence between scale of operations, machines and equipment, the quantity and quality of the labour input, the organization and management of the production process, and investment requirements. The evidence indicates that capital economies of scale should not be assumed to extend continuously across technologies. Neither open-pan nor vacuum-pan sugar manufacturing is technologically monolithic.

Open-pan sulphitation units, although preserving some artisan features, are not in the same class as gur processors equipped only with a bullock-driven crusher, a couple of pans and a few implements. Vacuum-pan factory capacities run from less than 100 to 26,000 tonnes of cane per day. Many older factories continue to operate with vintage equipment, and plants with relatively simple apparatus are still being built in some countries, despite the fashion for larger and more advanced designs. The standard vacuum-pan model now built in India has a crushing capacity of 1250 tonnes per day, which, barring a few exceptions, is smaller than new installations elsewhere.

The capital cost of sugar factories has risen sharply in recent years. Currently, budget estimates of $1000 or more per tonne of annual sugar output are being quoted for medium-sized vacuum-pan plants. It is true that the capacity of existing installations can be expanded up to a point at a fraction of the investment required for new factories. But the scale, cost and sophistication of conventional sugar processing technology has reached a stage where in some circumstances it is no longer viable at all and in not a few situations it is becoming increasing unattractive.

In retrospect, the withdrawal in the 1960s of several smaller Caribbean islands from sugar production for export, because they could no longer support even one factory of the size required to meet the competition on foreign markets, may be seen as a sign that mainstream technological development was proceeding in a direction that narrowed its economic appeal. The capital cost of establishing a new large-scale plantation-mill complex in a developing country has grown beyond the resources of private enterprise and can be financed only by governments and international lending agencies. Time profiles have lengthened as more years elapse between project inception and completion or until cane supplies are built up to match processing capacity. The greater the scale and complexity of a project, the greater the risk of delays in achieving the output targets and cash-flow projections on which the investment was premised. As a result of the increased scale of processing, sugar production has become more transport-intensive, since the yields of beet and cane per land unit have not risen to the same extent. In the absence of indigenous organizational and technical expertise, successful operation of large-scale enterprises depends on the retention of expatriate managers and technicians. Where domestic demand is small or the internal distribution network inadequate, financial viability is contingent on the fulfilment of foreign market and price expectations. To the extent that the technology of sugar production does not correspond to the level of development of its environment, there are less linkage opportunities, the amount of national value added diminishes, and the industry assumes the character of an enclave. Because of the different effects of scale on capital and labour requirements, larger sugar factories generate less employment per unit of capital invested. The changed capital/labour ratios moreover imply a shift in income distribution from rural areas to urban industrial centres.

With the evolution of economic thinking toward employment-oriented development strategies, the appropriateness of large-scale, capital-intensive sugar technology to the factor proportions found in many developing countries has come under scrutiny, primarily from the standpoint of factor inputs. The survival of small plants employing a great deal of manual labour in batch-type operations side by side with large factories equipped with the most modern labour-saving apparatus and continuous production systems began to appear in a new light as the attention of development economists turned to the employment-creating potential of small-scale sugar processing implicit in its labour-intensiveness. The comparison of different technologies has caused considerable difficulty, however, and the extent to which labour-intensive methods may be economically viable, except in special circumstances, has been a matter of some controversy.

The evaluation of technological alternatives in this field has to cope with a number of problems. A large amount of technical and economic data is available on the vacuum-pan sector of the industry. Nevertheless, gaps and inconsistencies appear and questions of representativeness and interpretation arise when it comes to using these data for purposes of technological comparison. By contrast, the fund of data on open-pan processing is small and narrowly based. Virtually all state-of-the-art reports and economic studies either directly relate to or are inspired by the Indian experience. While India is by far the largest producer of artisan sugars, the lack of data from such important centres as China and Colombia limits both technological and economic analysis. The course of technological change in Indian open-pan processing methods has been heavily influenced by the historical development of the Indian sugar industry and the particular political, social and legislative environment. To some extent, at least, this hindered the exploration of possible alternatives which might be more appropriate elsewhere. By extension, foreign assessments of the potential of small-scale sugar processing, insofar as they had an empirical basis, have been similarly circumscribed. Nevertheless, the studies of Indian sugar processing techniques have played a seminal role in raising the issue of appropriate technology in this field.

Technology itself has turned out to be an elusive concept when sought to be concretely applied, as in the comparison of different technologies. There are no simple, generally accepted rules defining the boundaries between technologies, the yardsticks for measuring them and their respective efficiency (another term with several meanings), and how these are to be used. In real life, different sugar processing technologies do not operate in such a similar manner as to allow facile comparisons; on the other hand, comparisons based on synthetic situations or a theoretical common denominator may neglect essential differences and become seriously biased.

Despite these difficulties, which temper the results of comparative studies of sugar processing technologies, certain general conclusions can be drawn. Measured against conventional vacuum-pan factories, current small-scale techniques employ less capital but require more cane, fuel and labour per tonne of sugar produced. Put in another way, a given investment in small-scale technology generates both more sugar and more work opportunities. Small-scale plants are less demanding in their skill and managerial requirements. The higher fuel consumption in processing may be offset by energy savings because of greater compatibility with nonmechanized sugar cane cultivation and shorter transport distances. While the best grades of sugar produced by small-scale methods approach the quality of vacuum-pan sugars, some types are not universally accepted by consumers and have a limited shelf life as well as only restricted application in food processing industries. Machinery and equipment for small-scale processing units are already being manufactured in a number of developing countries, and many items can be locally built by small workshops anywhere.

Until very recently, only a few Indian workers, as far as is known, have occupied themselves systematically with research and development in small-scale sugar processing techniques. The research and development effort directed toward small-scale processing has hardly been in proportion to its share in total sugar production, and to state that the possibilities of technical improvement at this level have not yet been fully explored is no disparagement of the advances achieved with very slender means. From what is known about the relative efficiencies of small and large-scale processing, it is clear that innovations should aim at improving the sugar recovery and fuel economy of small-scale technologies, i.e. making them less material-intensive, and raising the quality of the product, while preserving the advantages of low capital costs per unit of output and modest skill requirements. In addition, small-scale sugar processing techniques need to become more adjustable in their labour requirements. Whereas the extreme labour intensiveness of the small-scale methods now practised has its attraction in situatiors of heavy rural unemployment and low wage rates, inflexibly high labour requirements inevitably put in doubt, at least from the point of view of private profitability, the transferability of such methods to situations where the inverse relationship between unemployment and nominal wage rates is less pronounced. This calls for the expansion of the range of intermediate options currently available.

A new integrated system of juice evaporation that meets these criteria has been designed, and the first unit will be tested shortly. Independently of this, various devices and processes are being studied to determine their adaptability to small-scale sugar manufacturing. The first step has been taken to organize a regular exchange of information between the individuals and groups now actively engaged in research and development in this field in Europe as well as overseas. However, the imbalance between the resources devoted to research and development of large and small-scale production techniques is still enormous. In particular, small-scale heat and power generation and secondary product utilization need to become the subject of broadly conceived systems studies and adequately endowed development programmes.

Small-scale sugar manufacturing has shown a remarkable vitality. Notwithstanding the growth over the last hundred years of a modern sugar industry, processing sugar beet and cane with ever greater technical refinement in ever larger factories, artisan processors produce more sugar now than at any previous time. At the margin of mainstream Western-style technological development, an intermediate technology has emerged in the shape of the open-pan sulphitation plant. If this evolution is to proceed at a faster pace than hitherto and generate a range of feasible alternatives to suit conditions in different countries, it must be provided with the same kinds of institutional and regulatory supports that have promoted the world-wide diffusion of large-scale sugar processing techniques.

The time to start thinking about the appropriateness of different sugar processing technologies is at the outset of a sugar development programme and not at the evaluation stage of a particular project conceived in conventional terms. Processing, i.e. the factory phase, cannot be considered in isolation. The factory is but a segment of a system which, on the production side, consists of three intimately related parts: cane growing, cane transport, and cane processing. Two further components, distribution and marketing of the final products, complete the system. Because of the interdependence of the constituents of the system, their mutual compatibility needs to be closely examined not only in respect to their physical capacities but also with regard to the institutional characteristics. A sugar mill has been graphically described as a 'factory in the field'. The need to harvest the raw material at the optimum point of maturity and to process it without delay as well as the need to assure effective utilization of costly transport and factory equipment make organization a crucial factor in sugar production. As a rule, it is simpler and cheaper to increase sugar yield through better agricultural practices and proper coordination of harvesting and transport operations than by sophisticated equipment and procedures in the processing plant. Although there is a tendency to think that scarce organizational capabilities are best employed in a centralized manner in large-scale operations, it is not at all certain that this is true in sugar production. Here the experience indicates that organizational weaknesses are less obtrusive in systems sized to allow maximum scope for the display of local and individual initiative. Policy instruments, such as price, wage and fiscal regulations, have to be fashioned in such a way that they obstruct neither choice nor operation of the appropriate technology. An open-pan sulphitation plant, for example, cannot be expected to thrive if the market is allowed to become flooded with relatively cheap vacuum-pan sugar or if the price of noncentrifugal sugar is pegged at such a high level that it is more lucrative to discard the sulphitation apparatus, crystallizers and centrifugals, and produce an inferior grade of sugar. Questions such as these rather than the analysis of often rather fanciful output and cash flow projections lie at the heart of the selection process of the appropriate sugar technology.

2. Technologies and products

Sugar manufacturing in developing countries is mostly based on cane, and further discussion will be confined to the processing of this raw material. China is the only country where beet sugar plants processing as little as 5-10 tonnes of beet per day have been reported in the recent past (Hirschmüller and Delavier 1967), but nothing is known about the technology employed.

Millable sugar cane stalks are composed of approximately 75% water, the rest being divided about equally between fibre and soluble solids (Meade-Chen 1977). Of the soluble solids contained in the juice, sucrose accounts for 70-88% and the simple sugars glucose and fructose for another 4-8%. Unlike sugar beets, cane cannot be stored without excessive deterioration and must be processed as quickly as possible after harvesting.
Cane processing techniques and the resultant sugar products roughly divide into three categories:

a) open pan, noncentrifugal;

b) open pan, centrifugal;

c) vacuum pan, centrifugal.

Table 1 classifies the various types of sugar produced in the world in relation to the principal distinguishing characteristics of the respective processing technologies, which are briefly outlined below.

a) Open pan, noncentrifugal

The earliest tools employed to extract the juice from cane were probably mortar and pestle devices, at first operated manually, then by animal or water power. Screw and levered presses were widely used until superseded by the roller mill, invented some five hundred years ago. Early roller mills were made of stone or wood, later clad with iron, arranged vertically and powered by animals, water or wind.

Small upright iron mills, turned by a pair of oxen, are still the main piece of equipment used by tens of thousands of Asian and Latin American peasants in cottage-scale units processing up to 2 tonnes of cane per day. Extraction is poor, and generally a third or more of the sugar contained in the cane is lost in the bagasse, the fibrous residue remaining after milling. Larger farmers and urban entrepreneurs employ motor-driven horizontal crushers which allow a higher throughput with slightly better extraction efficiency. The extracted juice is boiled in shallow open pans heated directly by a bagasse or wood fire. Small amounts of chemical or vegetable clarificants are added to the hot juice and the scum rising to the surface is skimmed off. Boiling continues until a thick syrup with a dry matter content of about 95% is obtained. On reaching the striking point, at which sugar crystals form spontaneously i n the supersaturated liquid, the pan is removed from the fire and its contents cooled by vigorous stirring. Poured into moulds, the dense mass of fine crystals and syrup solidifies into blocks or cubes of a light to dark brown colour. Alternatively, a powder sugar is obtained by manual rubbing. The final product, known under various names, such as gur, jaggery and panela; depending on the locality, can be defined as a practically dehydrated raw cane juice. The technical efficiency of this cottage-level process is far lower than that of large-scale factories. The product yield of about 10% on cane is of a similar magnitude, however, because few of the nonsucrose components are removed from the juice.

The composition of this type of sugar product varies widely in accordance with the quality of the cane and the methods of processin Taste panel tests showed samples of Indian gur to be less sweet than factory-made sugar (Goswami 1952). However, in those areas of Asia and Latin America where noncentrifugal sugars are widely used, consumers are reported to consider a given quantity of artisan sugar to have the same utility as an equal amount of centrifugal sugar (Smith 1974). In Colombia, top-grade panela often sells at a premium over factory-produced white sugar (Junguito et 1. 1976).

Artisan noncentrifugal sugars are primarily destined for household consumption and because of the impurities they contain would have few direct applications in food manufacturing industries. Shelf life depends on the quality of the product and conditions of storage, but is generally limited.

b) Open pan, centrifugal

Similar methods have traditionally been employed in India to produce a fine-grained, white to yellowish-brown crystal sugar known as khandsari. This used to be made from rab, a massecuite obtained by open-pan boiling in the manner of gur, but less dense and more carefully purified, which was then subjected to a series of drainage operations to separate the molasses (Baxa and Bruhns 1967). The yield in final product from this procedure was extremely low in relation to the cane processed, and the industry was threatened with extinction until the introduction of small hand-operated or motor-driven centrifuges about fifty years ago raised the sugar recovery, the molasses resulting from the first and second centrifugal separations being reboiled to produce either inferior-grade khandsari or noncentrifugal gur.

For the last twenty years, much of the development work in artisan sugar processing techniques carried on in India has been directed toward perfecting a low-cost technology for the manufacture of a khandsari-type sugar approaching the quality of plantation white sugar, which would offer an economically viable alternative to large conventional sugar factories. The initial steps were taken by a team of the Planning Research and Action Institute of the Uttar Pradesh government in Lucknow, led by M.K. Garg, in collaboration with the National Sugar Institute, Kanpur, in the mid-1950s. Improvements in milling equipment and furnaces were incorporated in the design of a modern small-scale processing plant, the main new element of which was a scaled-down version of the lime sulphitation process of juice purification as practised in conventional sugar factories. For this reason, plants built after this design became known as open pan sulphitation (OPS) units (Anon.1965, 1966).

As it has evolved from the first pilot plant put into operation in 1956/57, a typical OPS unit of the present generation is equipped with two sets of cane knives and two three-roller mills with hydraulic loading to process 60 tonnes of cane per day or more. Still about 20% of the sucrose contained in the cane is lost in the bagasse, however. This is because the bagasse acts like a sponge, and no amount of dry milling can reduce the residue to anything other than an approximately equal mixture of fibre and juice. The extracted juice is purified by lime sulphitation, heating and settling taking place in open pans and tanks. Filter presses are used to treat the muds. The clear juice is concentrated in a series of open pans arranged over a furnace burning bagasse and wood. After having been boiled to maximum workable consistency, the massecuite is discharged to crystallizers fitted with a stirring device. Finally, the product is centrifuged and dried. As in traditional khandsari plants, the molasses from the first, second and often even the third centrifugal separations are reboiled. Because of technical limitations, sugar yields of OPS plants average about 7%, and though higher than the recovery rates of less well equipped, traditional khandsari producers, are below the level achieved by large-scale factories. The first product (roughly two-thirds of total output) approaches the quality of plantation white sugar made in vacuum-pan factories (Agarwal 1966; Baron 1975). The second, third and fourth OPS products are inferior and fetch correspondingly lower prices.

Many OPS plants have sprung up in India since the early 1960s. By 1973/74, their number was said to have grown to 1215 (Garg 1974; Armaingaud, Guérin and Michailof 1977). Total Indian centrifugal khandsari production is estimated to have reached 1.0-1.2 million tonnes in recent years, according to U.S. Department of Agriculture sources. There has not been, however, a massive transfer of OPS technology to other countries. The use of centrifugals, on the other hand, has not been confined to open pan sugar manufacturing in India. Engineering works in the Lyallpur area of Pakistan were said to be selling an estimated 350 hand-operated centrifugals annually in the 1950s (Pakistan 1958), and such equipment has also been reported in China (Hirschmüller and Delavier 1967).

c) Vacuum pan, centrifugal

The advances of mainstream sugar technology are mirrored in a long line of technical manuals, such as the Meade-Chen (formerly Spencer-Meade) Cane Sugar Handbook, now in its tenth edition, in which detailed descriptions of the equipment and practices used in large-scale sugar manufacturing may be found. A recent directory of cane sugar mills (Sugar y Azúcar Yearbook 1978) lists about 1500 installations in 82 countries and territories. Broadly speaking, all follow the same basic routine, but there are many variations and refinements. For this reason, only the main differences between standard open pan and vacuum pan plants are identified here.

Conventional cane sugar factories have mill trains consisting of up to seven three-roller units. To increase the extraction of sucrose, water or diluted juice is sprayed on the blanket of bagasse as it emerges from each but the last mill unit, a process termed imbibition. In the most efficient mills, less than 5% of the sugar in cane is lost in the bagasse. Imbibition is also possible in small-scale plants equipped with multiple mills; but it means that more water must be evaporated, and apart from higher fuel costs, it has been found that some of the sucrose gained by wet milling was lost again through inversion during boiling because of longer juice retention in the open pans.

In contrast to artisan installations, vacuum pan factories generate steam both for power and for juice heating and evaporation. Most of the water in the juice is evaporated in multiple effects consisting of a series of closed vessels (usually four) connected in such a way that the vapour outlet of one becomes the steam source of the next, with each succeeding vessel having a higher vacuum so that the juice boils at progressively lower temperatures as it passes through the set. By this arrangement, a given quantity of steam supplied to the first body will evaporate approximately as many times its weight of water as there are vessels in the set. Crystallization takes place in single-effect vacuum pans, also at a much lower temperature than in an open pan under atmospheric pressure. The advantage of lower boiling temperatures lies in less inversion and hence higher sucrose recovery as well as in less colour formation. While it is not possible to reduce the temperature of open-pan boiling, inversion losses and colour formation can be minimized by shortening the retention time.

Vacuum pan factories produce either raw sugar (a granular product usually containing 96% or more of sucrose and varying in appearance from light yellow to dark brown, which is further processed in separate refineries) or various direct consumption grades, ranging from 'turbinado', a light-coloured washed raw sugar, to 'plantation white', which at its best comes close to the quality of standard refined sugar. Vacuum pan factories recover about 10% (±2.5%) of sugar and 3% of final molasses per tonne of cane processed.

Figure 1 shows the approximate scale range of each of the main technological combinations outlined above. Globally, the structure of the conventional sugar industry has shifted toward fewer and larger units (Hagelberg 1976). In many countries, average plant size has trebled or quadrupled within the last forty years. In the view of some experts, the minimum economic capacity of new vacuum pan factories now lies at 1250 tonnes of cane per day. This is the size of the standard model now built in India. However, smaller factories can still be found even in countries that have become a byword for modern large-scale sugar processing, such as Argentina, the Dominican Republic and Mexico, and within the last ten years conventional sugar mills with capacities of 60, 300 and 400 tonnes of cane per day have been built in Rwanda, Gabon and Sierra Leone, respectively, according to industry journals. On the other hand, the upper boundaries of the size ranges shown in Figure 1 for noncentrifugal and centrifugal open pan installations are subject to change as a result of technical innovations.

Table 2 presents a simplified flow diagram of the processes involved in gur, khandsari and white sugar manufacture as well as approximate values for some operational parameters and product characteristics compiled from reports of operating conditions in India. As is to be expected, the figures for gur are the most variable, reflecting the wide differences in local practice.

Budget estimates of investment costs are subject to very wide variations, and values should be taken to indicate no more than the general order of magnitude. Based on Indian prices, the

Table 1: Sugar processing techniques and products

Boiling: / Finishing:	Open pan	Vacuum pan
Noncentrifugal	Gur, jaggery, panela, piloncillo, chancaca, papelon, rapadura, panocha, muscovado	Gur, panela in isolated cases
Centrifugal	Khandsari	Raw sugar Direct consumption sugars, e.g. turbinado, plantation white

Figure 1: Scale range of major technological combinations

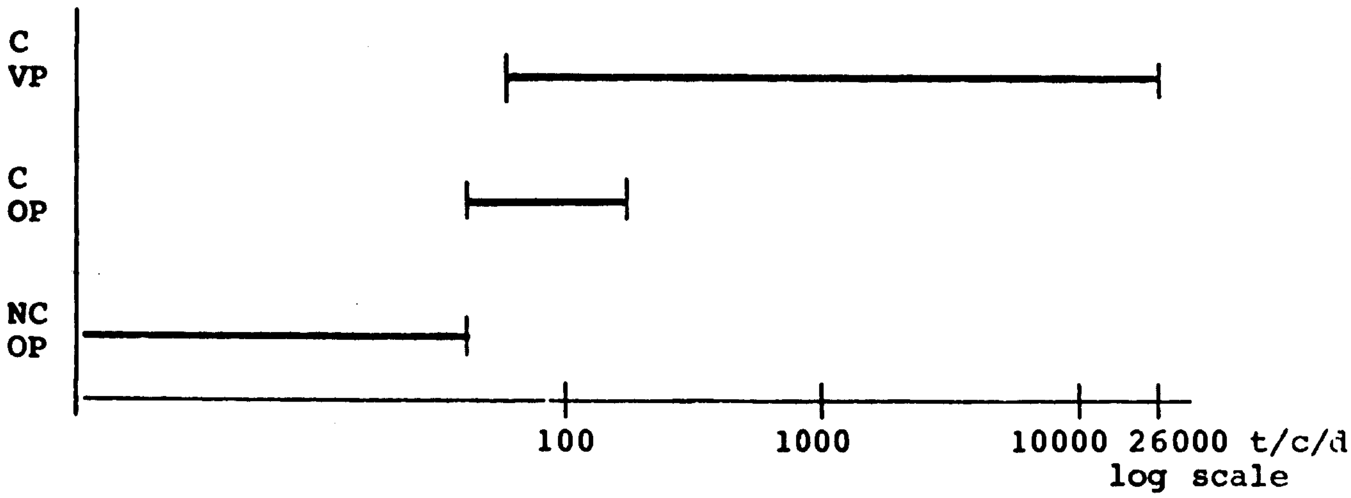
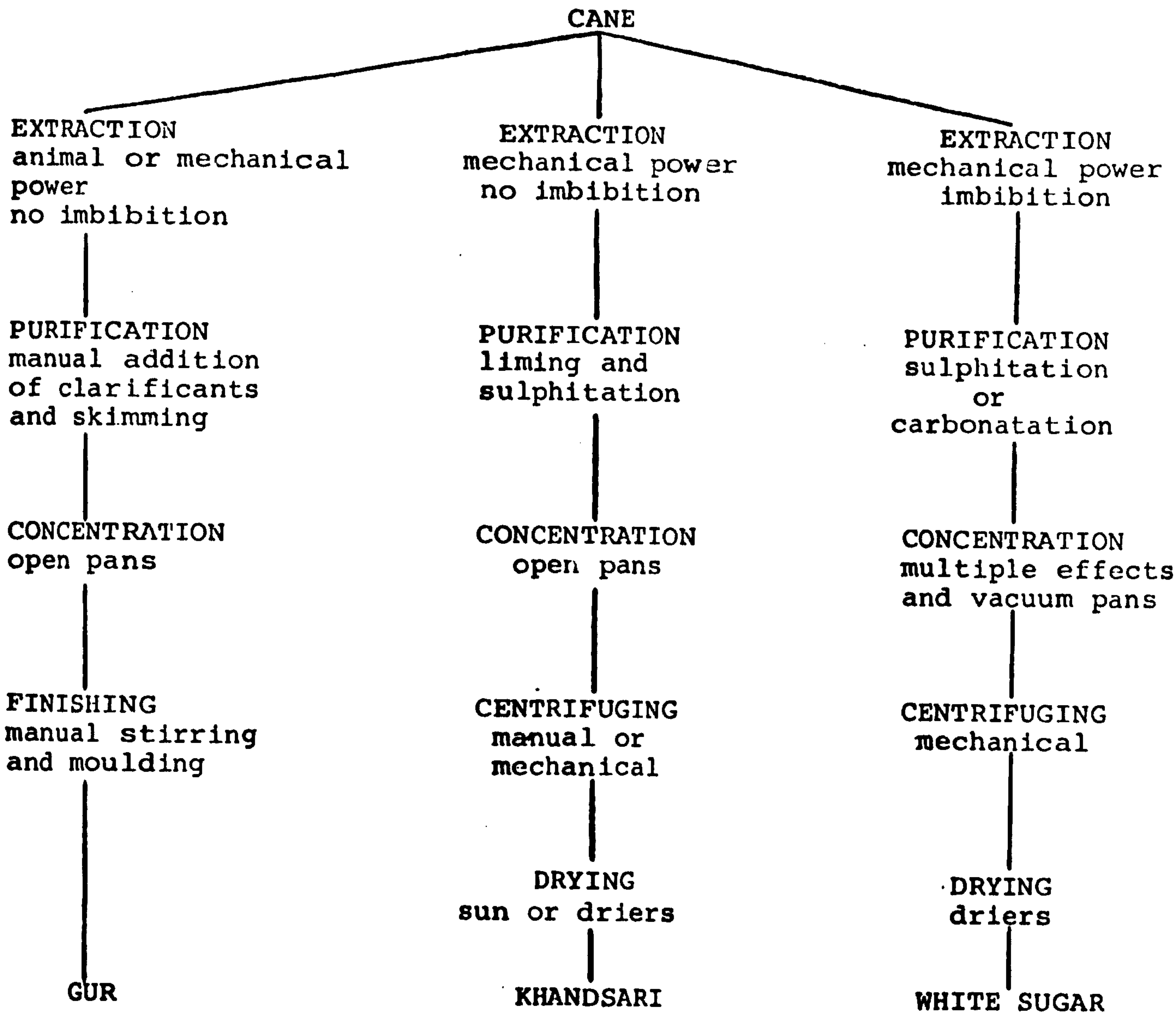


Table 2: Simplified flow diagram, operational parameters and product characteristics of gur, khandsari and white sugar manufacture in India



Characteristics	Gur	Khandsari	Plantation white
Scale of operations t/c/d	2	80	1250
Yield, product % cane	10	6-7.5	10
Product quality:			
Colour	brown	yellow/white	white
Sucrose, %	60-85	up to 99.8	up to 99.9
Reducing sugars, %	7-20	<1	<0.5
Ash, %	2-5	<1	<0.5
Moisture, %	3-10	<1	<0.5
Keeping quality	limited	good	good
Labour requirements, man-days/tonne output	30-50	20-30	10

capital cost of a gur unit with a motor-driven mill capable of processing 5 tonnes of cane in a 10-hour shift is estimated at less than $5,000. The capacity of open pan sulphitation plants is calculated on the basis of two-shift operation, and the capital cost of a plant milling 100 tonnes of cane per day is thought to lie in the neighbourhood of $225,000. For a vacuum pan factory operating round the clock and processing 1250 tonnes of cane per day, the estimated investment cost is upwards of $7.5 million. In terms either of cane milled or sugar produced, these figures indicate three quite distinct levels of capital costs. There is an inverse relationship between unit capital costs and unit labour requirements as shown for each technological system in Table 2.

Output data for the ten leading producers of artisan sugars and world totals as estimated by FAO and the US Foreign Agricultural Service are summarized in Table 3. For the reasons discussed in Hagelberg (1978), the two series are not directly comparable. Globally, however, FAO and FAS coincide in signalling the continued growth of artisan sugar production, although at a slower rate than the conventional sugar industry, and this trend is expected to be maintained in the foreseeable future (US Department of Agriculture 1977). Although India heads the list of artisan sugar producers by a wide margin, there are several other major centres of small-scale sugar manufacturing which so far have been virtually ignored by investigators.

3. Criteria for the comparison and evaluation of alternative sugar processing technologies

The assessment of technological alternatives is fraught with methodological problems. Some will already be apparent from the above outline of sugar processing techniques and products. Less

Table 3: Estimates of "noncentrifugal" sugar production (in 1000 tonnes)

	FAO				FAS			
	1961/65	1974	1975	1976	1967/68–1971/72	1974/75	1975/76	1976/77 (a)
India (b)	6,634	8,027	7,000	7,000	6,070	6,100	6,200	6,200
Pakistan	1,104	1,600	1,345	1,445	817	1,345	1,445	1,450
China	403	847	837	859	729	815	820	825
Colombia	653	700	557	687	688	557	687	859
Bangladesh	348	500	540	580	na	na	na	na
Thailand	132	350	350	360	241	350	370	700
Mexico	322	241	219	219	114	65	65	65
Indonesia	190	175	200	190	279	175	200	200
Brazil	282	140	140	140	330	200	200	200
Burma	148	130	130	135	144	130	135	138
World (c)	10,643	13,144	11,779	12,080	9,731	10,051	10,439	10,993

na) not available. a) preliminary. b) FAO figures include khandsari; FAS figures do not.
c) includes smaller producers identified by sources but not listed here.

Sources: FAO Production Yearbook, Vol. 30, 1976 (Rome 1977); United States Department of Agriculture, Foreign Agricultural Service, Foreign Agricultural Circular - Sugar, FS2-77, July 1977.

obvious problems emerge from the growing body of studies in this field (e.g., André and Fauconnier 1964a, b; Bischoff 1973; Garg 1974; Baron 1975; Pickett 1975; Alpine 1977a, b; Alpine and Duguid 1977; Armaingaud, Guerin and Michailof 1977; Forsyth 1977a, b). While differing in approach, these studies usually go beyond an interest in what is and pursue a normative objective of influencing policy and investment decisions, which makes it all the more important that the methodological problems be explicitly acknowledged.

As in other industries, investigations of alternative sugar processing technologies have been influenced by the problem of product homogeneity. Attention has focused on the OPS system as this produces a white sugar comparable to the plantation white of conventional factories. But the product is not entirely homogeneous. Only part of the OPS output approaches white sugar quality. The differences in quality are reflected in price differentials which, however, are subject to considerable regional variations and temporal fluctuations. Economic comparisons thus require more or less notional price adjustments that are difficult to substantiate because of insufficient information particularly with respect to the marketing of khandsari.

On the other hand, excessive preoccupation with product homogeneity may foreclose consideration of the technical and market potential of noncentrifugal processing systems and products. Until recently, the technical possibilities of modernizing the procedures and extending the size range of noncentrifugal sugar plants beyond the traditional cottage scale were little explored. Yet there may well be room for intermediate noncentrifugal sugar processing technologies, either to supply a superior household product, comparable in quality to high-grade Colombian panela or Brazilian amorphous sugar, or as a means of decentralizing milling operations and providing a semidurable concentrate for subsequent conversion to white sugar.

The problem of product homogeneity shrinks into insignificance in the face of the nonhomogeneity of plant, equipment and operating conditions. In every respect, wide variations are observed within both small-scale and large-scale sugar processing systems. This raises the question: which situations are to be considered as representative to calculate the differences in parameters? No one has proposed a satisfactory anwer, and the difficulties are illustrated by the bewildering variety of values collated from different studies. For example, Baron (1975), summarizing data supplied by M.K. Garg of the Planning Research and Action Institute, Lucknow, probably in 1972, put the total capital investment, including working capital, for an 80-tonne OPS plant at Rs.600,000; for a typical 1250-tonne vacuum pan factory built in 1973, the fixed capital investment (in land, buildings and machinery) was estimated at Rs.28 million. Armaingaud, Guérin and Michailof (1977) based their comparisons on an investment cost of Rs.2,095,000 for a 150-tonne OPS plant and of Rs.50 million for a 1250-tonne vacuum pan factory. A document of the Government of India Planning Commission, Project Analysis Division, entitled 'Choice of technology in the sugar industry', circulated at the Second UNIDO Consultative Group meeting on Appropriate Industrial Technology in June 1978, used a fixed capital cost estimate furnished by the Planning Research and Action Institute of Rs.1,222,000 for an 80-tonne OPS unit. Per tonne of daily crushing capacity, this figure is of the same order of magnitude as the French estimate but more than twice the figure cited by Baron. For a 1250-tonne vacuum pan factory, the Planning Commission cited fixed capital budget estimates ranging from Rs.58.5 to Rs.75.0 million.

Such differences are not entirely due to inflation. Similar variations exist in the estimates of manpower requirements. According to Baron (1975), a typical 80-tonne OPS plant was staffed by 9 permanent and 162 seasonal workers, a total of 171. The corresponding figures reported by the Planning Commission on the authority of the Planning Research and Action Institute are 9 and 191, a total of 200. On the other hand, Baron's calculations for the 1250-tonne vacuum pan factory were based on a labour force of about 900 (285 permanent and 630 seasonal), whereas the Planning Commission estimated total employment in a plant of this size at 720 (260 permanent and 460 seasonal). Both estimates are high by international standards and probably reflect the Indian practice of employing more men in administrative, materials-handling and maintenance jobs (Armaingaud, Guérin and Michailof 1977).

Comparisons of the actual operation of large and small-scale sugar processors in India start off from an unequal footing in that the average length of season of OPS units appears to be much shorter than that of vacuum pan factories. The figures usually cited are 100 days for the former and 130-140 days for the latter. Baron (1975) referred to an OPS crushing season from December to March, implying both a later start and an earlier finish than the normal season of vacuum pan factory operation, and saw the reason in the rural character of the seasonal labour force which left in April to harvest other crops. Armaingaud, Guérin and Michailof (1977), on the other hand, thought that OPS units probably had lower fixed overheads but higher marginal production costs than vacuum pan factories and for that reason tended to operate only during the period when the sugar content in cane is highest, a tendency reinforced by the system of taxation. In the conditions assumed, the respective break-even points of OPS and vacuum pan plants were estimated to be about 60 and 100 days. If this is so, it implies that OPS units are exposed to a smaller risk of insufficient cane supplies and have a greater potential of improving their relative standing if a reduction in the marginal costs of production (e.g., early and late maturing cane varieties, greater labour productivity and better fuel economy) were to allow them to prolong their milling season.

Alpine and Duguid (1977) postulated equal basic rates of pay for daily rated staff in small and large-scale sugar processing units. But this does not conform to Indian practice. According to Baron (1975), a typical modern mill paid each employee four times as much per annum (Rs.2450) as the average OPS unit (Rs.684). A certain disparity would be expected to result from the different ratios of permanent and seasonal workers as well as the difference in the length of the milling season mentioned above, apart from differences in the levels of skill and qualification. More importantly, however, as Baron noted, the large-scale plant constitutes an enclave of the manufacturing sector in a rural area, with wage rates that are related not to those of agricultural jobs but rather to those in other manufacturing industries. By contrast, the smaller OPS plant harmonizes much more with its environment. Armaingaud and his colleagues reported that unskilled workers in OPS plants received only about half the wage rate obtaining in vacuum pan factories due to the absence of trade union organization and the availability of underemployed and undemanding rural labour. The Indian Planning Commission study estimated the daily wage scales for unskilled labour at Rs.5 and Rs.10 for OPS and vacuum pan plants respectively. In addition, the latter paid seasonal workers a retainer in the inactive period, a point also noted by Baron. As a result of the wage differentials, Baron and the French investigators found that although OPS plants required two or three times the labour time per tonne of sugar as vacuum pan factories, the wage costs per unit of output were more or less equal. The Indian Planning Commission diverged here in presenting substantially lower wage costs per unit of output for the vacuum pan factory, possibly as a result of the different manning levels assumed. Be that as it may, the Indian experience suggests that comparisons of sugar processing techniques must take into account not only different man-day/output ratios but also different wage rates and differences in the character of the work force.

A common practice in comparing large and small-scale sugar processing technologies is to calculate the number of small-scale plants equivalent to one large-scale factory in terms of sugar output or capital input. A variant of this is to calculate the capital, labour and other inputs required to produce a given quantity of sugar with alternative technologies. For example, on the simplified assumptions that

	OPS plant	Vacuum pan factory
Fixed capital cost	$250,000	$7,500,000
Number of workers	180	720
Sugar output	750t	15,000t

then,

1 vacuum pan factory = 30 OPS plants in terms of fixed capital cost
= 20 OPS plants in terms of sugar output.

Hence, the sugar output from a capital investment of $7,500,000 is

in 1 vacuum pan factory: 15,000 tonnes
in 30 OPS plants : 22,500 tonnes

and a capital investment of $7,500,000 generates employment for

in 1 vacuum pan factory: 720 men
in 30 OPS plants : 5,400 men.

Conversely, to provide 15,000 tonnes of sugar requires by

vacuum pan technology: $7,500,000
720 men

OPS technology : $5,000,000
3,600 men.

Of course, in a wider context the comparison is not as simple as that. While having approximately the same sweetener and food values as factory-made sugar, khandsari is inferior in other quality characteristics and cannot expect to command the same price. More important is the lower process efficiency of present OPS technology in terms of cane and fuel. Whereas a vacuum pan factory, roughly speaking, requires 10 tonnes of cane to produce 1 tonne of sugar, the OPS plant requires 14 tonnes, the difference being somewhat mitigated by a higher final molasses yield, provided there is a suitable outlet for this by-product. Assuming an agricultural yield of 50 tonnes of cane per hectare, this means that 3,000 hectares of cane have to be grown and harvested to produce 15,000 tonnes of sugar in a vacuum pan factory, while for the same quantity of OPS sugar the cane from 4,200 hectares is needed. Similarly, whereas a modern vacuum pan factory is self-sufficient in fuel and should even accumulate a surplus of bagasse, an OPS plant needs additional energy inputs in the form of purchased electric power or diesel oil as well as firewood.

On the other hand, small-scale plants enjoy an obvious advantage over large factories in that the capital cost of building an equivalent number in terms of sugar output is not only absolutely lower but also less lumpy. The construction programme of, say, twenty small plants can be phased more flexibly in line with the growth of local capabilities than a large-scale project. This touches upon the general question of the assumptions concerning capacity utilization involved in calculations like those presented above as well as in attempts at more rigorous comparisons of the profitability of large and small-scale sugar processing plants by discounted cash flow analysis generating net present values. Reference has already been made to the different lengths of the operating seasons of OPS and vacuum pan plants in India, their different break-even points and the relative risk of being affected by insufficient cane supplies that these imply. As Baron has pointed out, the argument that OPS units are 'cane wasters' by comparison with large-scale mills because of their lower recovery rate is a valid one, but mills that do not operate near their rated capacity because of lack of cane may equally well be dubbed 'capital wasters'. This remark, made with reference to harvest fluctuations in India, where cane production is long established, is even more germane to new cane-growing regions. It recalls to mind the advice of the well-known American sugar technologist Emile C. Freeland that it was not economically sound to erect large-size sugar factories in areas where the development of sufficient cane supplies would take a number of years and that pending the creation of the necessary agricultural capability for a large mill, it was better to install small factories with very much lower first cost and overhead (Pakistan 1958). One must further ask whether the two systems are equally prone to be affected in their operational performance by unplanned stoppages, such as machinery breakdowns. Intuitively, the risk that output assumptions will not be fulfilled for this reason appears greater in the case of one large factory than in that of the equivalent number of small plants, but there are no comparative data.

From the foregoing discussion it will be apparent that the choice of sugar processing techniques entails consideration of a fairly large set of parameters. In addition to differences in product quality and capital and labour requirements, the ranking of technological alternatives in this field is influenced by the recovery rate, the length of the operating season, the utilization of installed capacity, fuel consumption, the level of cane and sugar prices, and wage rates. In Baron's social cost-benefit analysis, the discount rate emerged as a key parameter, on which depends the social value attached to a unit of investment. Armaingaud and his colleagues demonstrated the crucial importance of fiscal and marketing advantages to the private profitability of OPS plants in India.

Clearly there are a number of trade-offs, and where the balance lies is determined by public policy and the specific circumstances. The price of greater process efficiency (i.e. a better cane/sugar conversion ratio and fuel economy), product quality and labour productivity is a higher capital requirement. With capital as the constraint, output and employment can be maximized at the cost of land. At least in India, the evidence indicates a choice to be made between paying industrial wage scales to a smaller number of workers for more months of the year or lower wages to a far greater number for a shorter period.

Several other factors may influence the choice of sugar manufacturing techniques. India, has become largely self-sufficient in sugar mill equipment, although some items are still imported or manufactured under foreign licence. But the foreign exchange drain caused by the remaining imports, royalty payments and dividend remittances is increasingly compensated by machinery exports (Chatterjee 1972). In this case, small-scale sugar processing plants with their simpler equipment needs merely create a market for smaller provincial machine shops. In less developed countries, however, the choice of processing technology means the difference between having to import virtually all the equipment or being able to make a large part locally. Similarly, India has the technical, managerial and organizational know-how for the operation of large-size vacuum pan factories. In newer sugar-producing areas, on the other hand, the scale and degree of sophistication of the processing plant chosen may determine whether it can be efficiently run by locals or must depend for a long time on foreign expertise. In India, finally, both large and small-scale processing installations are linked to small cane growers. Many vacuum pan factories are indeed owned by grower cooperatives. Labour-intensive methods of cane agriculture, relying largely on animal power, are thus combined with relatively capital-intensive methods of sugar manufacturing. This is quite different from the picture presented by some recent sugar development projects in Africa. There, as Armaingaud, Guérin and Michailof (1977) observed, because of inability or unwillingness to assume the burdens of organizing a complicated outgrower system, the construction of large sugar factories has entailed the establishment of mechanized and irrigated plantations to guaranty the cane supply and assure the viability of the industrial investment. The selection of a large-scale capital-intensive processing technology set up a vicious circle, since less capital-demanding dry-farming methods might have been perfectly feasible on a smaller scale.

4. Directions of research and development in the field of intermediate sugar processing technologies

From the comparison of the currently available technologies, certain criteria emerge that should guide the further development of small-scale techniques:

1) The present advantage of small-scale sugar technologies of low capital cost per unit of output needs to be preserved.

2) The relatively low level of technical, managerial and organizational skill requirements should be maintained. Innovations in the methods of juice purification and concentration should allow the 'art' of the sugar boiler to be replaced as far as possible by more easily acquired operational routines.

3) Technological development should concentrate on improving
   --sugar recovery,
   --fuel economy,
   --labour productivity,
   --product quality.

4) Technological systems for small-scale sugar processing must be flexible and adaptable to a wide spectrum of local conditions and requirements.

Together with these considerations, the state of the art and the availability of suitable machinery and equipment in India and elsewhere indicate certain priorities. Standard milling units manufactured in India, consisting of two sets of cane knives and two three-roller crushers with intermediate carrier, as well as Indian-made crystallizers and centrifugals are serviceable and reasonably priced.

A matter of some urgency, on the other hand, particularly with a view to technology transfers, is the improvement of the present Indian procedures for juice purification and concentration. Even in India, the commitment to sulphitation implies a perennial import requirement of an increasingly expensive material input. In a small plant, it is difficult to escape the unpleasant smell of sulphur dioxide. The inevitable sulphur dioxide residue in the final product is unwholesome, although where the sugar is manufactured in unhygienic conditions, its biocidal action is on balance an advantage. As has been noted, open-pan boiling, while cheap in terms of capital investment, has several drawbacks: excessive fuel consumption (even with the existing improved furnaces, OPS producers are believed to need as much as 10 tonnes of firewood per 100 tonnes of cane in addition to the bagasse), considerable sucrose losses due to inversion and caramelization, and high labour requirements.

For these reasons, it was decided in the first instance to explore alternative methods of juice purification and concentration. Miniaturization of the vacuum evaporation techniques employed in large sugar factories was ruled out for the time being because at the level of scale contemplated it was likely to result in an unacceptable increase in the capital cost per unit of output. An intermediate solution was sought, which would raise the technical efficiency of small-scale sugar manufacture without greatly adding to the cost and complexity of the process.

This orientation has resulted in the design of two core systems which are adaptable to a wide range of requirements with respect to scale of operations and type of sugar produced. The first (Figure 2) is a scheme for the production of noncentrifugal block sugar in plants processing 20-300 tonnes of cane per day. The second (Figure 3) is designed to produce a washed direct consumption sugar similar to plantation white in plants crushing 100-300 tonnes of cane per day.

Liming and phosphatation are used to purify the raw juice in the basic model of a block sugar plant (Figure 2), the scum rising to the surface being skimmed off. For the production of a plantation-white grade of consumption sugar, the middle juice is

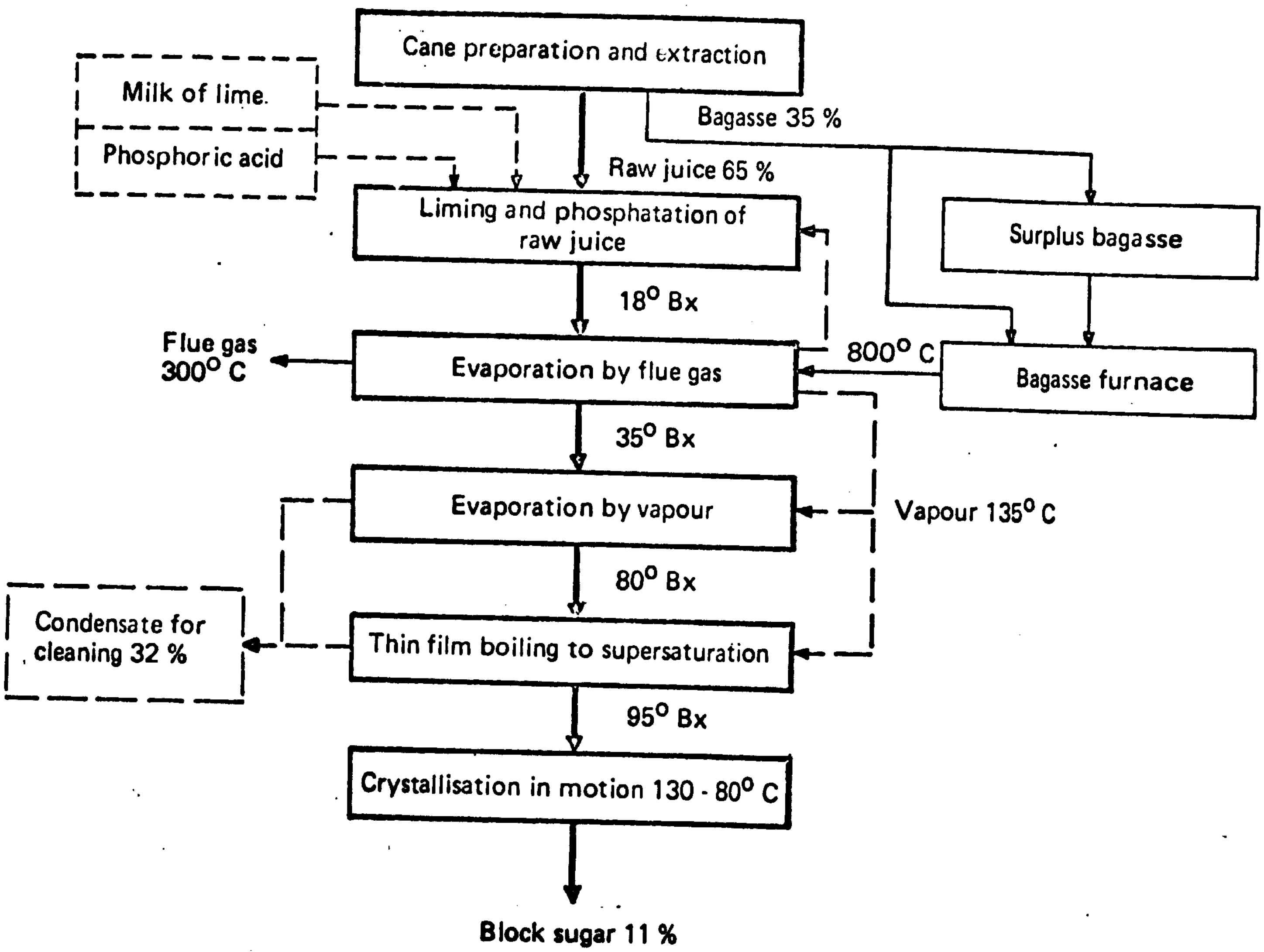


Figure 2: Intermediate technology for manufacture of block sugar

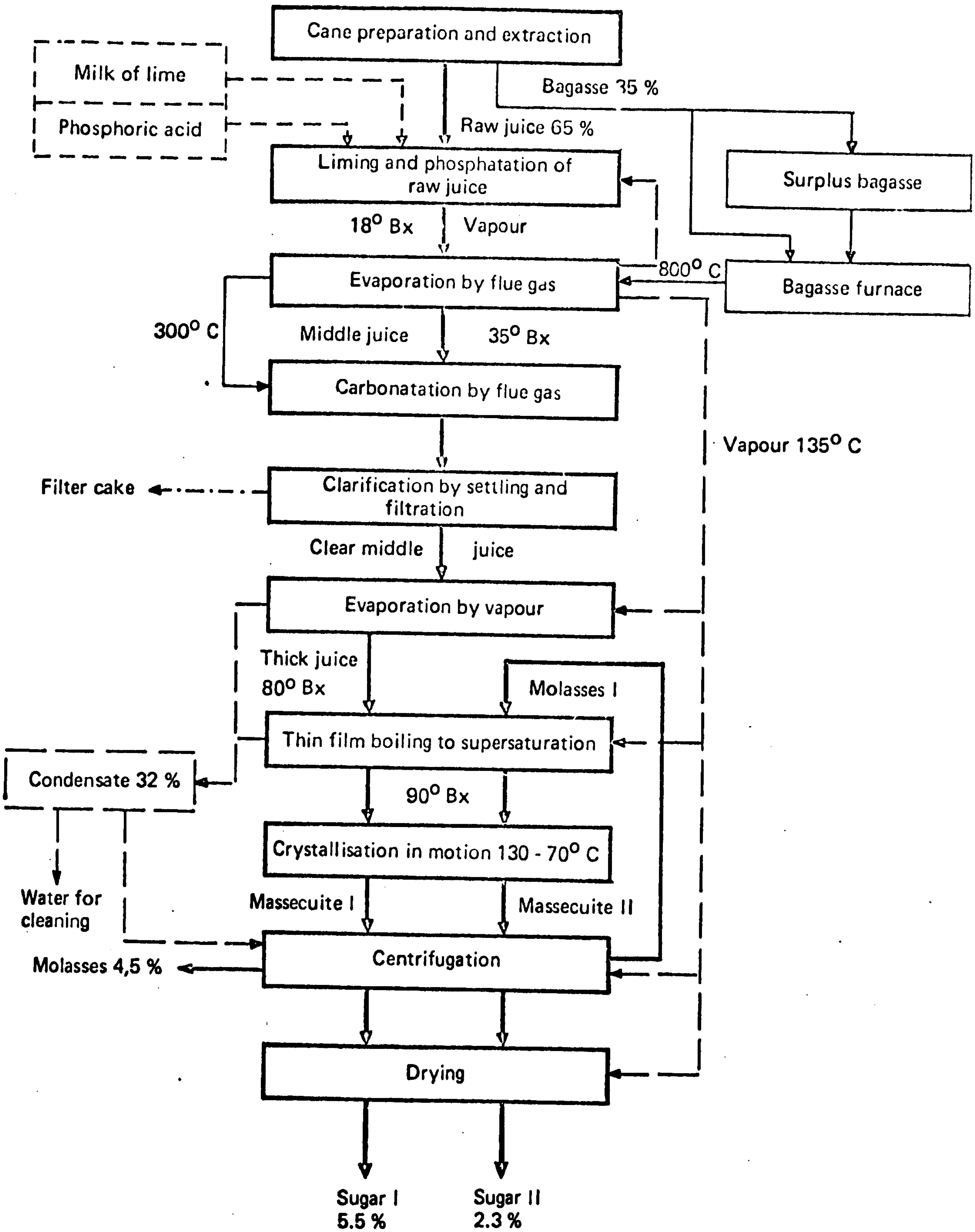
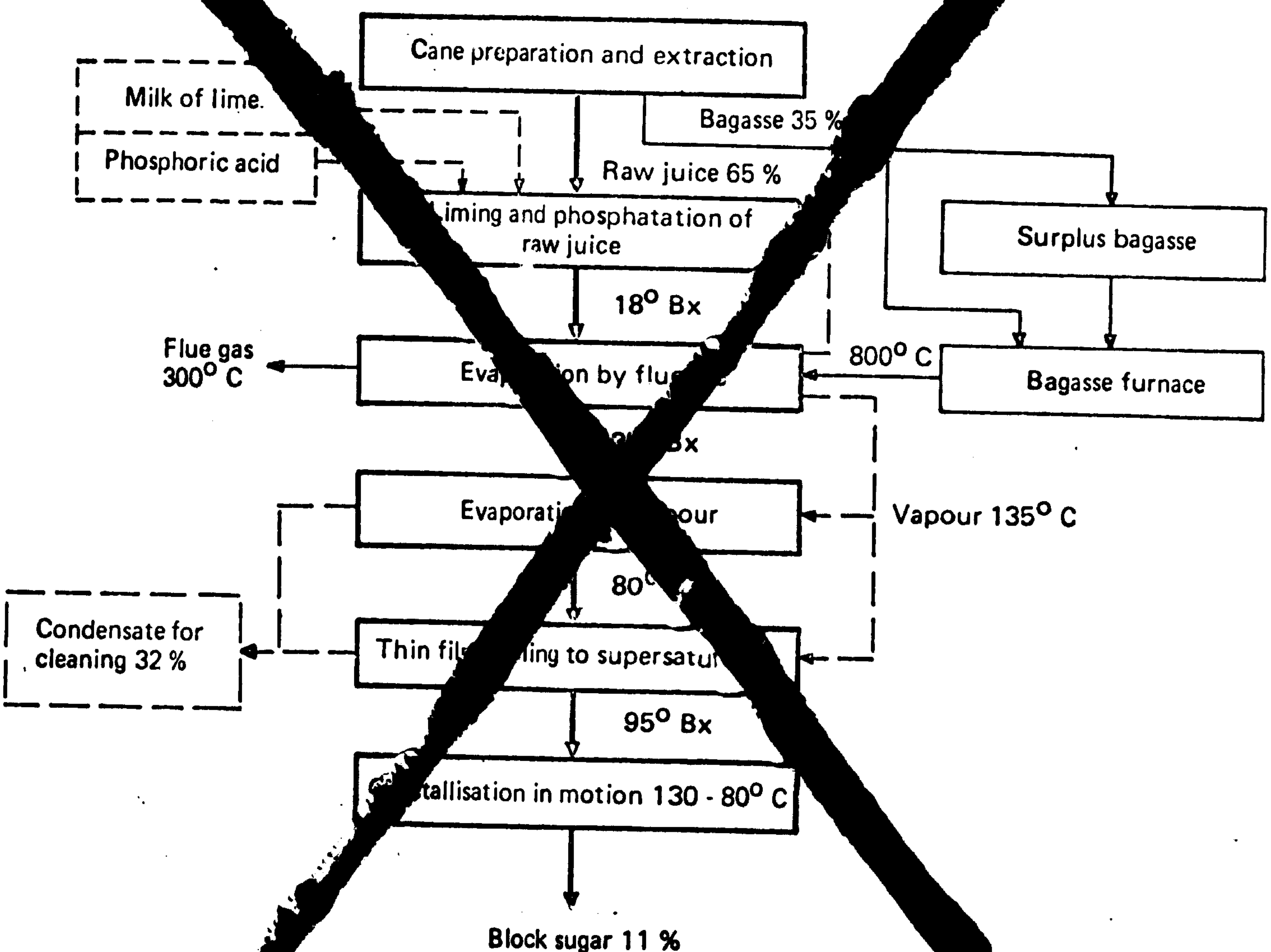


Figure 3: Intermediate technology for manufacture of washed direct consumption sugar



Fi[illegible]e 2: Intermediate technology for manufacture of block sug[illegible]

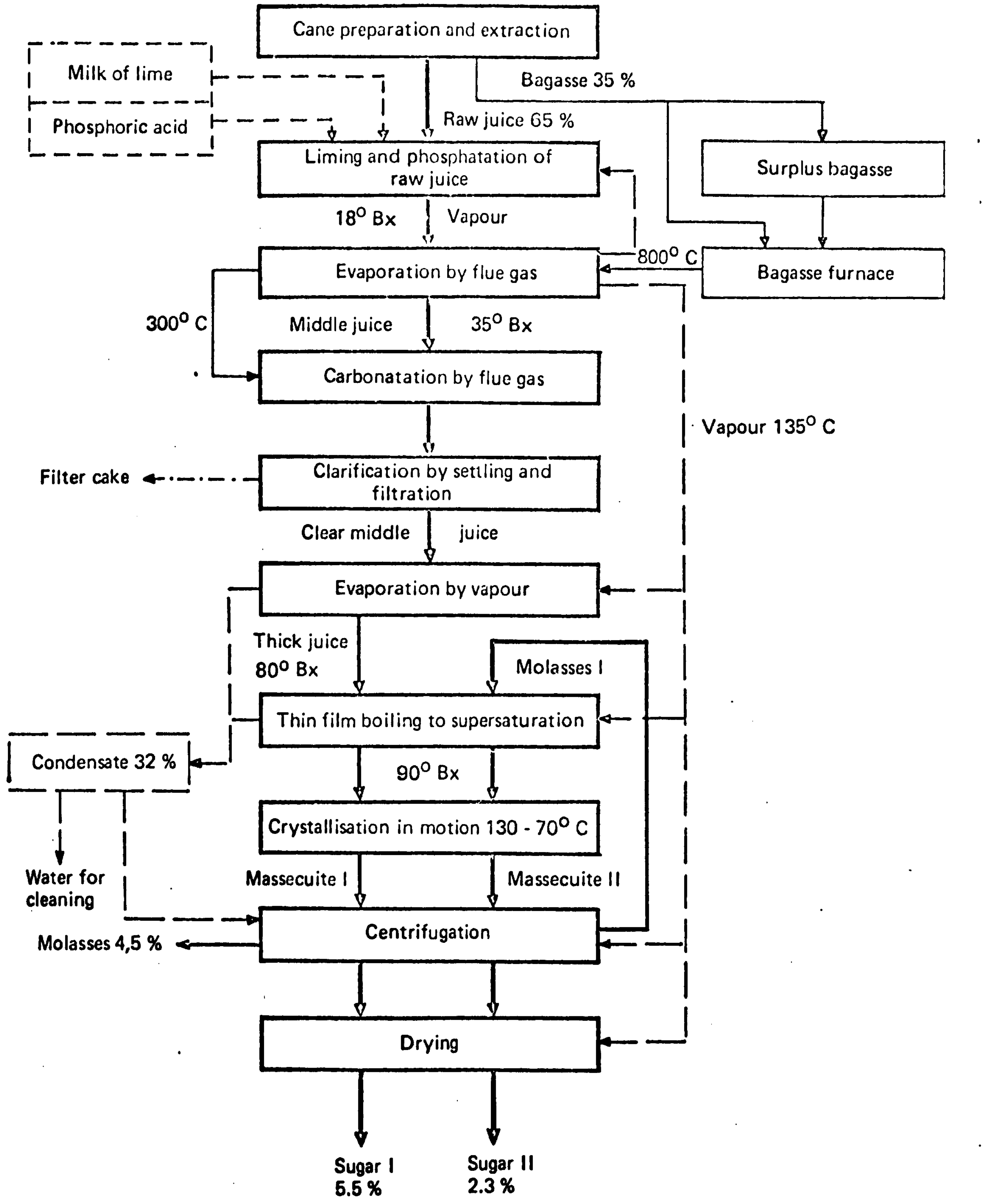


Figure 3: Intermediate technology for manufacture of washed direct consumption sugar

subjected to further purification by flue-gas carbonatation and settling (Figure 3).

Both basic models employ a three-stage flue-gas/vapour system of evaporation. In the first stage, the juice is concentrated from 18 to 35 °Brix (percentage by weight of solid matter in solution) in a vertical short-tube calandria evaporator heated by flue gas. Either directly (model 1) or after carbonatation and settling (model 2), the middle juice is further concentrated to 80 °Brix in a vapour-heated Robert-type open evaporator. In the final stage, a thin-film evaporator (vertical cylinder type with scrapers mounted on a central revolving shaft and external steam jacket) is employed to carry concentration to 90 or 95 °Brix, depending on whether block or granulated sugar is produced. To make block sugar, the massecuite, after crystallization in an air-cooled crystallizer with revolving helix, is poured into moulds. For granulated sugar, the massecuite is discharged to a centrifugal, where the sugar is washed with steam and hot water before passing to a vapour-heated drier. The steam for the second and third stages of the evaporation process and for washing and drying of the crystals is supplied by the vapour produced in the first evaporation stage.

Although item for item the evaporation equipment described is more expensive than that used in open-pan plants, total capital investment costs are likely to be higher only in the lower part of the size range mentioned. This is mainly because there is only one furnace in the new design instead of the multiple furnaces required in all but the small gur installations (processing less than 5 tonnes of cane per day). The resultant space saving translates into a substantial reduction of civil construction costs, particularly in more remote regions lacking a local supply of building materials.

The changes in purification methods entail several advantages. There is a net gain in operational simplicity. The cumbersome sulphur burner is eliminated and the drawbacks of the use of sulphur dioxide referred to earlier are avoided. The carbon dioxide has zero cost as it is contained in the flue gas, and superphosphate, commonly used as a fertilizer, is relatively cheap and widely available. If the filter cake in which the phosphate compounds leave the plant is applied to the cane fields to be taken up by the next crop, a phosphate cycle is established. The replacement of sulphur in khandsari manufacture was investigated by Gupta, Ramaiah and Agarwal (1966) who found that phosphates were equally efficient in the removal of colouring matter and the inhibition of colour formation.

The evaporation system outlined makes the process semi-continuous. Shorter retention times and less exposure to high temperatures are expected to reduce sucrose losses due to inversion and caramelization during boiling by one half to two thirds as compared with present open-pan systems. More uniform crystal formation as a result of more continuous operation and greater control of conditions also improves the quality of the product, as does the availability of vapour and clean hot water to wash the sugar during centrifugation.

One of the main objections to open-pan boiling -- excessive fuel consumption -- is overcome. The consolidation of the multiple furnaces into one reduces radiation losses and in conjunction with the evaporators used makes for better heat transmission. The residual heat of the flue gas is utilized in the carbonatation. The flue-gas/vapour combination represents a simple form of multiple evaporation. Altogether, these changes reduce fuel requirements by at least one half.

The labour input is reduced by at least a quarter in comparison with the customary open-pan methods. The process is still considerably more labour-intensive and less skill-demanding than large-scale technologies and thus offers greater employment opportunities. At the same time, the reduction of labour requirements to a truly intermediate level and the improvement of working conditions render it more widely applicable and increase its attractiveness in all those situations where even the critics of small-scale sugar processing concede its usefulness (cf. Forsyth 1977b). The range of application is further extended by the fact that the new technology opens the door to subsequent increases in labour productivity. The consolidation of the multiple furnaces into one, for example, makes possible the mechanization of bagasse transport and feeding, should circumstances so require.

Greater flexibility is also given in the type of sugar produced. Gur-type sugars can be manufactured by standard open-pan boiling techniques in plants processing more than 30 tonnes of cane per day, as shown by the existence in several countries of larger installations producing these kinds of sugar (e.g. Ramos Núñez 1959). Nevertheless, noncentrifugal sugar production in open-pan furnaces of the Indian type runs into the problem that output can be increased only by multiplying the number of furnaces. The evaporation system outlined here extends the range of block sugar production to 300 tonnes of cane per day, employing only one furnace.

Secondly, the new technology offers the possibility of the stepwise conversion of block sugar plants with a capacity of 60 tonnes or more to the production of washed-raw and plantation-white-grade

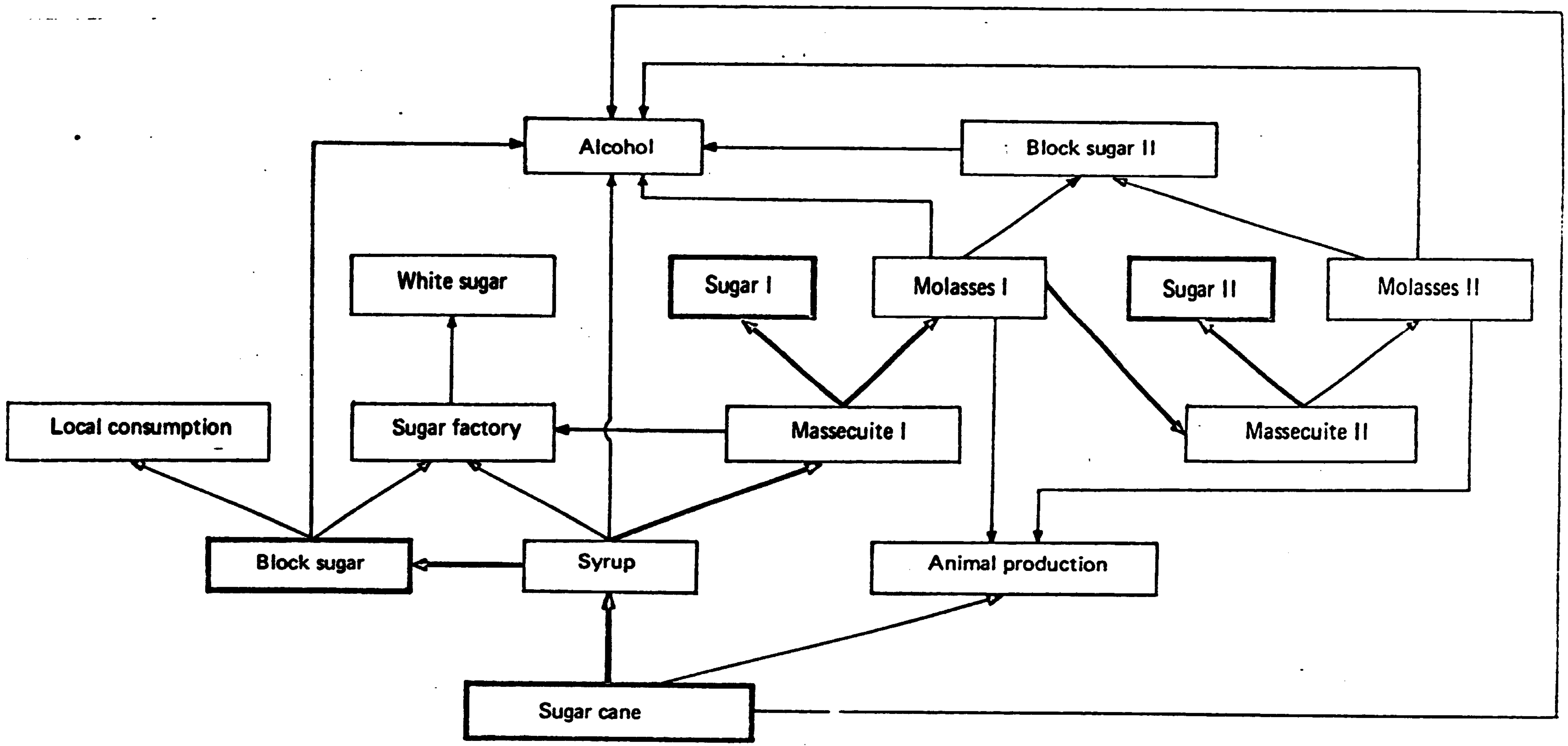


Figure 4: Alternatives of sujar cane utilization

sugars. With defecation by liming and phosphatation, only crystallizers and centrifugals need be added in the first instance in order to enable a block sugar plant to produce a washed-raw-grade sugar. At a later stage, carbonatation can be added to produce a plantation-white grade. Conversely, plants laid out for the manufacture of washed direct consumption sugar can also process their molasses to block sugar (see Figure 4), which is fit for human consumption since it is free of sulphur dioxide.

Figure 4 shows how the two basic models described fit into different production systems. Depending on local conditions, block sugar may either be marketed directly or processed to white sugar in a conventional sugar factory or refinery. So-called neutral gur (pH 7.0) was made in India specifically for refining (Roy 1951). In Thailand, both noncentrifugal 'red' sugar and syrup are reprocessed in larger sugar factories (Hirschmüller and Delavier 1970). In Venezuela, several small mills now produce only syrup which is trucked to conventional factories for further processing (Cordovez 1974). Such procedures may be adopted for various reasons: consumer preferences, transport savings effected by shipping a product of higher unit value, the relative perishability of the different products, better utilization of installed sugar factory capacities (Padalkar, Mantri and Karmarkar 1964), and/or higher returns to the sugar cane growers. Similarly, the conversion of molasses I to so-called molassine gur has been a common practice in Indian khandsari factories (Roy 1951). The channelling of relatively high-grade materials, such as molasses I and II, to alcohol production is based on the notion that it may be more economical to crystallize and market only the most easily obtainable fraction of the total sugar and utilize the rest in fermentation (Hickson 1977). The feasibility of linkages with various branches of animal production is well established in theory and practice (e.g. Preston 1974).

The plant designs described here incorporate several elements of standard modern small-scale sugar technology, such as the currently available extraction units. These, too, however, are subject to innovation as a result of ongoing research and development efforts. A meeting on research and development perspectives in small-scale sugar processing, held in London under the auspices of Intermediate Technology Development Group in May 1978, reviewed the work in progress in various areas.

One of the main objectives at this point is to increase the efficiency of extraction in small plants. Several approaches have been suggested to this end:

--Design of a five-roller crusher unit for dry milling, eliminating the intermediate carrier now located between two three-roller crushers.

--Replacement of the crushers by hammer mill shredders and screw presses.

--Utilization of the fibre-pith separation process (Laurie, James and Mayers 1973) with subsequent extraction of the juice by pressure.

--Reconsideration of wet milling in light of the removal of the constraints imposed by open-pan boiling on imbibition following the development of the flue-gas/vapour evaporation process.

A substantial improvement in the technical efficiency of the evaporation process may well be achieved without fundamentally departing from the principle of open-pan boiling and at no greater capital cost by the introduction of North American maple syrup evaporators. Economically, this type of equipment appears to be particularly suitable for plants at the lower end of the scale range discussed here.

At the crystallization stage, better control of crystal formation may possibly be obtained by an adaptation of the seeding procedure practised in large-scale factories or by passing the oversaturated syrup through a colloid mill or homogenizer (Nicol 1974).

The improvement in heat economy and the acceleration of the evaporation process made possible by the designs outlined above open two major avenues of further development in intermediate sugar processing technology. One is in juice extraction. As noted earlier, there is an absolute limit to the extraction efficiency that can be achieved by dry milling, due to the spongy nature of the fibrous residue. The simple multiple evaporation obtained by a flue-gas/vapour combination clears the way for the application of imbibition, probably in conjunction with the addition of a third three-roller mill unit. This can be expected to bring a 10-percent increase in sucrose recovery at the cost of a relatively small additional capital investment.

Secondly, the availability of vapour from the first evaporation stage constitutes an invitation to explore further changes in the boiling process. Without going to the length of attempting to miniaturize the entire vacuum-boiling system of large sugar factories, there is likely to be considerable advantage in creating a slight vacuum in the crystallization stage by the simple expedient of a steam jet condenser. In this case, the thin-film evaporator employed in the present designs (Figures 2 and 3) for the final concentration would be replaced by cheaper conventional vacuum pans. Thanks to the vacuum, the final boiling would take place at a lower temperature, resulting in less sucrose decomposition.

Crystal quality would also be improved since more of the crystal growth would take place in the vacuum pan, where it is more easily controllable, rather than during cooling in the crystallizer, as now happens in khandsari manufacture.

All possible improvements in the heat economy of the evaporation process do not, however, eliminate the dependence of small-scale sugar processors on an outside supply of fuel or power for the generation of mechanical energy, as in contrast to large factories, no steam is produced for prime movers. This problem could be solved by the adaptation to intermediate-level sugar processing of a producer gas generator utilizing bagasse (Tromp 1940). The gas is used to drive an engine, while the heat produced during its generation as well as the waste heat from the motor go to evaporate the juice. The coupling of power and heat generation represents a highly efficient utilization of the energy value of the bagasse.

This outline of research and development in progress and envisaged shows the wide scope for improvements in intermediate sugar processing technologies. Given only a fraction of the support currently going to R&D in large-scale, capital-intensive techniques, it is not at all beyond the bounds of technical possibility to provide competitive intermediate alternatives for a variety of situations.

5. Policy conclusions

There can be few industries in the world today that display a greater technological pluralism than sugar manufacturing. Its fundamental processes are performed by techniques extending over a wide spectrum of scale and sophistication. Economic research has failed to identify one particular set of techniques that is universally appropriate in the sense that it minimizes private and social costs in all circumstances. Modern large-scale sugar factories are a triumph of technical efficiency. But their escalating capital cost increases the risk of economic failure, particularly when the design is transferred from the Western environment which inspired it to less developed countries. Notwithstanding the lower technical performance of the small-scale and intermediate technologies until now available, they have had a strong claim to consideration as viable alternatives in cases of insufficient or dispersed cane supplies, small domestic market, inadequate infrastructure, severe capital constraint, and/or high rural unemployment. This claim is enhanced and extended to a wider range of situations by the innovations described in this paper, which are currently in process of implementation. These greatly enlarge the opportunities for multiple-objective development strategies that combine the aims of increasing sugar production with employment generation and economy in the use of capital, land and energy.

It has often been said that politics more than economics has determined the cast of world sugar production and trade. The choice of sugar processing techniques, too, is in the final analysis a governmental decision in that directly or indirectly it is determined by the system of fiscal incentives and protections, price regulations and wage controls. Intermediate technology in this field has advanced to a point where policy makers in diverse situations have a real choice.

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