



HAL
open science

The sugar industry: The cradle of modern Bio-Industry ((Biotech Highlight))

John Villadsen

► **To cite this version:**

John Villadsen. The sugar industry: The cradle of modern Bio-Industry ((Biotech Highlight)).
Biotechnology Journal, 2009, 4 (5), pp.620-n/a. 10.1002/biot.200800318 . hal-00484126

HAL Id: hal-00484126

<https://hal.science/hal-00484126>

Submitted on 18 May 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



**The sugar industry: The cradle of modern Bio-Industry
(Biotech Highlight)**

Journal:	<i>Biotechnology Journal</i>
Manuscript ID:	BIOT-2008-0318.R1
Wiley - Manuscript type:	Other contribution
Date Submitted by the Author:	07-Apr-2009
Complete List of Authors:	Villadsen, John



Review

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Biotech Highlight ((8979 words))

The Sugar Industry- the Cradle of modern Bio-Industry

John Villadsen

Department of Chemical and Biochemical Engineering, Technical University of Denmark, Building 229, Lyngby, 2800 Denmark

jv@kt.dtu.dk

Keywords: Cane and beet sugar. Slavery and free labor. Vacuum pans. Crystallizers. Continuous sugar extraction. Sugar as a platform chemical.

Global sugar production has reached an astonishing level, increasing almost linearly from 100 M tons in 1988 to more than 165 M tons in 2008/09. At a bulk price of about 320 US \$ per ton (2008) sugar is one of the dominant products of the agricultural sector, and it is a major factor in the economies of Brazil, India and China. The *per capita* consumption of sugar is rapidly increasing in newly industrialized countries, a trend that mirrors the development in Europe and in the USA during the 19th century, where the *per capita* consumption is now stagnating or even decreasing. A new role for sugar is, however, emerging, namely as raw material for the chemical industry, a substitute for oil and gas. At the present a large fraction of the sugar produced (more than 30 % of the Brazilian cane sugar production, 34.5 M tons in 2008) is used to produce ethanol for transportation fuel, but ethanol from lignocellulosic biomass will hopefully replace ethanol both from starch and from sugar itself. Sugar is much too valuable to be used for anything but human consumption and as a raw material for commodity chemicals in the polymer, solvents and health care market.

Standing on the threshold of what many believe to be a new beginning for the sugar industry it may be instructive to look back on the history of European sugar production, first in the European overseas empires from the time of the discovery of the New World, and next from the turn of the 19th century on the European continent. In the history of sugar production we shall find the origin of many of those technologies that shaped the development of both Chemical Engineering and Biochemical Engineering. Especially since sugar production came to Europe the ingenuity of engineers and scientists have constantly pushed the productivity in the field and in the factory to new and astounding heights. In the accumulated experience of the sugar industry lies the key to the leading role that this industry will play in tomorrows use of sugar as raw material for commodity chemicals.

There is also a dark side to the history of sugar production. Sugar came to influence the political thinking of European nations for more than 400 years. It led to mercantile conflicts that spanned all oceans and continents, and it led to the formation of industrial

1
2
3 cartels fighting for dominance of the sugar market with bribes and bounties, and with the
4 covert participation of political and commercial elites.

5 First and foremost it brought infinite suffering to millions of people who were forcibly
6 removed from their home countries to work in sugar plantations. The monstrous profits of
7 sugar merchants and the emergence of prosperous cities in Europe were paid with the
8 blood and sweat of these people.
9
10

11 1. The Caribbean sugar bowl and European commerce. 12 13

14 Since the 13th century sugar cane, imported by the crusaders from Palestine and Egypt,
15 had been grown in Andalusia and Sicily, but an earnest European involvement in sugar
16 production started when Columbus brought cane from the Canaries (or Madeira) to
17 Hispaniola on his second journey in 1493. Hispaniola, the large island now shared
18 between Haiti and the Dominican Republic, became the cradle of the Caribbean sugar
19 adventure, and in 1516 the first sugar mill was established in the island to rationalize the
20 primitive methods of extracting the juice by crushing of the cane in wooden equipment.
21 Large quantities of impure sugar could now be exported to Europe to be refined into a
22 commodity product. The Spaniards early recognized sugar production as a glorious
23 opportunity and a substitute for the lack of gold in their early New World colonies. The
24 industry had a large demand for capital, an input not readily available in Spain. The
25 country squandered the fabulous initial fortune in noble metals from its mainland
26 American colonies on endless, and in the end futile wars in Europe. Another essential
27 input was labor. The original inhabitants of the Antilles were decimated after a few
28 decades of exploitation, and conscribed or contracted labor from Europe proved to be
29 unfit to do the hard work in the sugar cane fields and in the *trapiche* (oxen driven) mills
30 and *ingenio* (more efficient, water powered) mills that produced 800 vs. 400 kg sugar/day
31 for older mills. Here started the import and exploitation of African slave labor that
32 continued for almost 400 years (until 1880 in Cuba). It brought endless sufferings to
33 millions of people, and it is at the root of almost all the weakness that is so obvious in the
34 present day economies of the small, independent Caribbean nations.
35
36
37
38

39 Slaves from Africa had been available since about 1460, after Portugal had established
40 trading stations in Guinea. The importation of Negroes to the Spanish possessions in
41 Hispaniola, Cuba and Puerto Rico started in 1505, and from 1517 contracts were made
42 for yearly transport of several thousand slaves from West Africa to the West Indies. The
43 mass slaughter of the indigenous population by war, fevers or by hard labor had reduced
44 the population of the Large Antilles from about 300 000 in 1493 to 14 000 in 1514, but
45 the number of imported slaves far surpassed the population growth. The state supported
46 sugar *encomiendas* found to their surprise that Negroes died just as fast as Amerindians,
47 but in the case of Negroes an unlimited supply was available from Africa.
48
49

50 The Spanish trade monopoly in the New World was challenged by the Dutch, the English
51 and the French. What started as piracy and the plundering of treasure fleets and Spanish
52 cities in the New World evolved into a policy of colonizing the outskirts of the Spanish
53 empire: The Dutch in Guyana and in Brazil, the French in Guadeloupe, Martinique and
54 the part of the Guyana known as Cayenne, and the British, first in Virginia, the Carolinas
55 and Barbados, and next in Jamaica (conquered in 1655 from Spain) and in various small
56 Caribbean islands.
57
58
59
60

1
2
3 At first all the West European colonies were settled by white people, growing tobacco for
4 export and tropical crops for subsistence. But within a period of 20 years from the 1640's
5 the small farms of the Caribbean islands had been converted into large sugar plantations.
6 Dutch technicians who had developed the incipient sugar industry in Brazil were evicted
7 as a result of the wars between Holland and Spain, and they gladly moved their expertise
8 from Brazil to the British and French possessions in the Caribbean.

9
10 In the thirty years of transience from a sustainable economy, primarily based on self-
11 sufficiency, to an economy based on a monoculture of sugar the Windward Islands
12 experienced a dramatic ethnographic change, from societies predominantly of European
13 extraction to societies where Negroes outnumbered Whites by up to 10 to 1.

14 Barbados is an example of the change. The colonization of Barbados in 1629 was
15 financed by private merchant companies just as was the first colonization of Virginia and
16 the Carolinas. They had access to sufficient capital on the North European markets to
17 start sugar production on a scale that soon out-competed the poorly financed Spanish
18 plantations. The small island of Barbados (460 km²) became "the Jewel in the Crown" of
19 Great Britain in the late 17th century, creating enormous profits to planters and to
20 refineries in England. In the 1650's, the densely populated little island, on 745 large
21 plantations worked by about 85000 slaves, remitted sugar to England worth over 3
22 million £ [1, p.112] . Land increased fabulously in price, from 400 £ for a plantation of
23 200 ha in 1640 to 14 000 £ in 1648. The trade with the island employed 400 ships, and in
24 England small towns such as Bristol and Liverpool developed into thriving commercial
25 centers for sugar refinery and for trade on the Triangular Route between England, West
26 Africa and the colonies in the Caribbean. Goods manufactured in England during the first
27 industrial revolution were sent to Africa, slaves to the Caribbean, and sugar to the
28 increasingly sophisticated refineries in England. Nantes and Bordeaux in France owed
29 their phenomenal growth in the 18th century to the same trade and industries as Bristol
30 and Liverpool¹.

31 For almost two centuries, from 1620 and until after the Napoleonic wars, Mercantilism
32 dominated European economic thinking. The Navigation Act of the 1650's was an
33 attempt by England to restrict the commerce with the New World to British ships. It
34 spawned 30 years of wars between the Dutch and their British and French competitors
35 until The Dutch finally acceded defeat in the late 1690's. Thereafter, and until after the
36 Revolutionary wars 1793-1815 France and Great Britain continued the struggle for trade
37 dominance, using the Caribbean sugar islands as pawns and trophies. This struggle was
38 enacted on the background of rivalries, between the individual possessions of the two
39 nations. When a hurricane hit Antigua in the Leeward Islands, Barbados rejoiced because

40
41
42
43
44
45
46
47 ¹ References [1] and [2] have greatly influenced the opinion of the present author
48 as regards the initial rewards and the ultimate disaster of European activities in
49 the Caribbean. Greed, cynicism and sanguinity on the part of planters and their
50 European financiers was finally punished when new technology exposed the
51 inadequacy of the colonial economies. A shameful trail of human degradation and
52 suffering is all that is left.

53
54 Eric Williams (1911-1981), a renowned economic historian, was the first prime
55 minister of independent Trinidad and Tobago, from 1962 to 1981.
56
57
58
59
60

1
2
3 the price of Barbadian sugar increased. When in 1763 France finally conceded defeat in
4 the Seven Years War it was happy to cede “the snowy acres of Canada” while retaining
5 possession of the sugar islands, Guadeloupe, Martinique and St Lucia. But in reality the
6 outcome of this particular land grab was mediated by the political lobby of planters from
7 Barbados who feared an added competition on the protected British market from sugar
8 grown in “new” British colonies in the West Indies [1, p.130]. In 1752 200 000 ha was
9 cultivated in Jamaica, but 800 000 ha of easily cultivable land lay idle because the
10 absentee planters living on English country estates saw no purpose of increasing
11 production at the risk of a slump in sales price. During the last half of the 18th century the
12 French sugar cultivation on the 27500 km² virgin soils of their colony St Domingue,
13 acquired from Spain in 1731 by partitioning Hispaniola at the present boundary between
14 Haiti and the Dominican Republic, amounted to much more than the total sugar
15 production from all British West Indian colonies. Rather than responding by increasing
16 production in Jamaica or in their new possessions Trinidad, captured from Spain in 1797,
17 and British Guyana, captured from the Dutch in 1799, the planters proposed the
18 Government to invade St Domingue and destroy its sugar production. The British
19 invasion of St Domingue ended in a costly fiasco, and a subsequent attempt by Napoleon
20 to restore St Domingue to slavery based sugar production ended in a humiliating defeat of
21 crack French troops to the insurgent slaves who managed to create in 1804 the first
22 independent state, Haiti, in the Caribbean.

23
24 Denmark, a midget in comparison with Great Britain and France, entered the fray when it
25 bought St Croix from the French in 1733 (as a “reward” for cynically supporting the
26 French in the war of the Polish Succession against Austria). The previous Danish
27 possessions of St Thomas and St Jan were unsuited for intensive sugar production, but
28 the gently rolling hills of St Croix were ideal [2]. Expanding on previous French, Spanish
29 and English cultivations on the island, by 1754 virtually its whole surface of 212 km² had
30 been planted with cane (figure 1). At the end of the 18th century sugar from St Croix was
31 refined at 13 places in Copenhagen, and refined sugar accounted for more than 50 % of
32 the total exports from Copenhagen to the Baltic Sea countries [3, p.408-9]. Although on a
33 much smaller scale than that of Great Britain, the Danish slave trade from Africa to the
34 Danish West Indies and the transport of sugar from the islands was the foundation of a
35 fabulous mercantile adventure in the late 18th century. Danish pretensions to play for high
36 stakes in the trade game did, however, lead to severe frictions with Great Britain and
37 eventually led to the disasters that hit Denmark during the Napoleonic wars, resulting in
38 bankruptcy of the state and the loss of Norway.

39
40 In fact the old European sugar empires in the Caribbean were all doomed at the entry to
41 the 19th century. With few exceptions (one far sighted Jamaican planter introduced the
42 steam engine in 1768) their production methods were still those of the 17th century, based
43 on animal, water or wind power, and with a “free” and inexhaustible supply of
44 manpower, the slaves, to compensate for a lack of interest in technology development.
45 The imminent threat to the sugar islands was the abolishment of the slave trade (1807) in
46 Great Britain which was slowly enforced around 1830.

47
48 After emancipation of the slaves (Great Britain in 1833, France, Denmark and Holland in
49 the wake of the 1848 revolutions) indentured labor from India and the Dutch East Indian
50 colonies was conjured up to save the Caribbean sugar production. But the cost of
51 transportation of workers and their families on 5 year contracts, the unwillingness of the
52
53
54
55
56
57
58
59
60

laborers to work themselves to death in the sugar plantations, and the steady attrition due to illness and death of the imported labor proved the failure of substituting cheap labor for capital and modern technology. The East Indian immigration from around 1835 has shaped the multicultural societies of the modern Caribbean nations with all the richness of their culture, but with a latent threat to their internal coherence. It did, however, not save the sugar economies of the British, French or Dutch Caribbean dominions. Having argued their case for fifty years, planters from the Indian subcontinent finally convinced Parliament, against fierce opposition from the West Indian lobby, that Indian sugar should be imported to England with the same preferential status as Caribbean sugar. This opened up for the import of huge quantities of cheap cane sugar from British India. In the Caribbean a massive influx of Anglo-Saxon capital to the Spanish colony of Cuba rapidly transformed Cuban sugar production. The sugar estates were extensive with areas up to several thousand hectares, and the sugar was extracted with the use of steam power in huge central factories that dwarfed the factories of Jamaica and Barbados. Thus around 1850 sugar production (223 000 tons per year [1, p.361]) in Cuba surpassed the total production from the British West Indies, and by 1894 the Cuban production of 1.05 M tons [1, p.366] was more than twice as large as that from the rest of the Caribbean where even the large and fertile sugar colonies, British Guiana and Trinidad, had started their decline.

The deadliest threat to tropical sugar was, however, the emergence of European sugar. The first sample of refined sugar from sugar beets was presented to the Prussian king in 1799 by Franz Karl Achard, director of the Prussian Academy of Science in Berlin, and grown on his own estates in Silesia. The first manual of beet-sugar growth was also from 1799, figure 2 [4]. It is alleged that the British Government offered Achard a bribe of 30 000 £ to report a failure of his process [1, p.243], but events soon proved Achard right to uphold his scientific integrity. From 1807 the British blockade of Napoleonic Europe led to a rapid establishment of large scale sugar production in Germany and especially in France.

2. The growth and triumph of beet sugar during the 19th century.

At the end of the Napoleonic wars the infant European sugar industry suffered a heavy setback with the resumption of import of colonial sugar. But the commitment was too large for the enterprise to fail. In France by 1811 32000 ha was planted with sugar beets of a new and better variety than Achards. In 1813, the year before the downfall of Napoleon, a climax was reached with a production of 3500 ton refined sugar in 300 refineries, of which the most prominent was Établissements Say, one of the predecessor companies of the present day French sugar giant Eridania Béghin-Say [5]. A yearly production of 3500 t sugar was not much compared to a French colonial production of 150000 t before the wars, but slowly the French sugar production increased due to better cultivation methods for sugar beets and to the adaption of rational sugar extraction methods which soon made the colonial production look antiquated. Between 1800 and 1840 the sugar content of the beet increased from 2-3 % to almost 10%. Tropical sugar had to be shipped to Europe at the high freight rates that prevailed before the advent of large tonnage steam powered ships led to a dramatic reduction of transportation costs. It had to be refined in Europe to satisfy the demands of increasingly

1
2
3 sophisticated customers. Finally, the slave worked plantations in the West Indies operated
4 under an increasing threat of riots and revolts that sometimes flared up and led to loss of
5 property and life. Conversely, the work force of the sugar growers in North Western
6 France became increasingly self confident, spurred by better education, exposure to
7 “modern” technology, and the emerging trade unions. In 1839, when about 500 highly
8 capitalized factories in France produced an annual 48 000 ton beet sugar [1, p.385], the
9 domestic sugar interests simply became more important to the state than the colonial
10 economies. Their spokesmen in the *Chambre des Députés* could outvote the deputies
11 from the *Départements d’outre mèr* who represented the colonial planters, and taxation of
12 domestic sugar was relaxed.

13
14 The British continued to import subsidized sugar from their colonies, from their Cuban
15 business associates, and slowly also from Brazil. British beet sugar production was never
16 seriously considered until the U-boat blockade of World War 1. It developed slowly
17 between the World Wars, and it saved the country from sugar “famine” between 1939
18 and 1945. Now [6], the United Kingdom ranks fourth in European sugar beet production.
19 After 1840 Germany became a leader in the development of European sugar production.
20 A protected beet sugar industry which was not ham-strung by obligations to colonial
21 empires, rapidly spread from Prussia to other North German states, for example to the
22 Kingdom of Hannover [7]. Everywhere sugar beet cultivation led to a rapid development
23 of the rural economies. At a time when the hoe was still used for tilling in many West
24 Indian plantations worked by emancipated slaves or measly paid East Indians, the heavy
25 plough or even steam driven ploughs were introduced. The beet pulp, the remainder of
26 the sugar beet after extraction of the sugar, was dried and became an excellent cattle feed,
27 rich in proteins, carbohydrates and minerals. This byproduct was almost as valuable as
28 the sugar, and when cheap grain from North America and Russia threatened to disrupt the
29 traditional rural economy it greatly assisted the development in North West Europe of
30 cattle production for meat, and especially for dairy products. .

31
32 The birth of a modern rural economy improved the national coherence and it employed
33 previously underemployed rural workers in the sugar factories and in the subsidiary rural
34 industries. The scale of production was small compared to the scale of modern sugar
35 factories, but thousands became enrolled in the Industrial Society, creating a mutual
36 dependence through trade and manufacture between country and large cities.
37 Under the umbrella of heavy import tariffs the German sugar industry boomed after 1860,
38 and with a production of more than 2 million t in 1871 the domestic market was covered,
39 and a gigantic export business started. Originally, taxation of domestic sugar was
40 intended as an important source of internal revenue, but since the taxation on beet sugar
41 was based on a hypothetical yield of sugar from the beet it became a powerful incentive for
42 improvement of the whole sugar sector in the 1860’s. This was the driving force for an
43 enormous capitalization of the German sugar industry. Between 1870 and 1895 it was
44 “the tail that wagged the dog”, and the policies of the *Kaiserreich* became increasingly
45 subservient to the large industries, not least the sugar industry [8]. Internal sugar price
46 was increased through taxation, and the revenue was used to subsidize export of sugar at
47 cut-rate prices.

48
49 Around 1900 Europe, spearheaded by Germany, but with participation from Russia and
50 Austria, sent more than 7 M ton sugar on the market, about 2/3 of the world sugar
51 production.
52
53
54
55
56
57
58
59
60

1
2
3 At this time the sugar economies of British and French overseas dominions were
4 bankrupt. Indian sugar was seriously hurt, and even the capital intensive Cuban sugar
5 production was suffering-in part, however, due to the disastrous destructions wrought on
6 the country by the wars of independence in the late 1890's. The United States, recipient
7 of more than one third of German sugar export [8], started to impose import duties on
8 sugar that more than equaled the subsidy given to export sugar from Germany. There was
9 a public outcry against German policy, such as "Big German Sugar Trust-said to threaten
10 the industry of all other countries" [9]. These sentiments, although grossly overstating the
11 facts, contributed to poison international relations in the years leading up to World War 1.
12 The United States had its own slowly developing beet sugar industry to protect, and the
13 US also had to tender for the old slave grown sugar from Louisiana, Hawaiian sugar,
14 grown and harvested by coolies from the Philippines, and sugar from the new dominion,
15 Puerto Rico. Semi-independent Cuba, run by US capital, also sent huge quantities of
16 sugar to the US market.

17
18 In the end international opinion, led by an outraged British free-trade-economy (with
19 "special obligations" towards the British Empire!), forced the Brussels convention of
20 1902 on all the sugar growing countries [8, 15]. All export subsidies were abolished and
21 import duties reduced. The result was a collapse of the German sugar industry which had
22 exported more than 50 % of its production, but Russian and Austrian sugar was hit
23 equally hard. On the positive side the German government broke the Sugar Trust (*die*
24 *Zucker Kartellen*) which had held the strings of German fiscal policy, and which had
25 become a general threat to the very important German export to the British market.

26
27 The policies of the large European sugar producers, especially Germany, had some very
28 interesting repercussions for the sugar industry in the smaller countries, Holland, Sweden
29 and Denmark. Denmark is an illustrative example. Here beet sugar production was
30 introduced in 1872 as part of the belated industrial revolution that followed in the wake
31 of the calamitous war of 1864 with Germany and Austria. In the midst of a deep set
32 national disillusion a few far-sighted Danish businessmen, led by the industrialist and
33 international banker Carl Frederik Tietgen (1829-1901), built up a Danish industrial
34 empire modeled on British limited companies and heavily financed internationally.
35 Tietgen created a Danish food and transport empire. Danish railways, a fleet of ocean
36 going freighters and a harbor for export of Danish meat and dairy products, Esbjerg in
37 southern Jutland, to compensate for the harbors in Schleswig-Holstein lost in the 1864
38 war. His Great Nordic Telegraph Company eventually monopolized the European
39 telegraph communications with China and Japan, and finally, The Danish Sugar
40 Company (*De Danske Sukkerfabrikker, DDS*) became a lighthouse for Danish Chemical
41 Technology.

42
43 With the democratic constitution of 1849 the Danish government had lost all interest in
44 the Danish West Indies. The revenue from importation of Danish colonial sugar became
45 inconsequential in the revitalized Danish economy, and the tropical islands were soon
46 offered for sale. The post Civil War US showed an interest in acquiring Caribbean
47 possessions, but Congress did not close the deal until 1917 when the completion of the
48 Panama Canal in 1914 required a deep protective zone.

49
50 After a modest start (9000 ton beets on 375 ha, and a sugar production of 1000 tons) in
51 1874 the Danish sugar production reached 135000 tons grown on 6700 ha in 1912. After
52
53
54
55
56
57
58
59
60

1
2
3 1890 this was enough to supply the Danish population with domestic sugar, even when
4 the per person consumption increased from about 10 to 40 kg per year [10]².

5 The reasons for its survival during the onslaught of cheap, heavily subsidized sugar from
6 Germany are manifold, but important factors were the *corps d'esprit* of well educated
7 Danish growers, a close cooperation between industry and Danish academic institutions,
8 and finally the remarkable resilience of DDS which was vertically and horizontally
9 integrated in the whole pre-World War 1 Danish industrial structure.

10 The contributions of Danish technology to the development of sugar production, not only
11 from beet but also from cane, will be included in the next section. 70 years of continued
12 technological development made Danish sugar production the most effective in the world
13 during the last half of the 20th century. It was an important contributor to the spread of
14 Danish Engineering and later Danish Biotechnology to the rest of the world.
15
16
17
18
19

20 Decline of beet sugar through the globalization of trade at the end of the 20th
21 century.
22
23

24 In the decade from the Brussels convention to the 1st World War Central European-and to
25 a certain degree French sugar industry-was in disarray. The German sugar trust fell apart,
26 infighting started between overproducing companies, and bankruptcies were common in
27 an industry which had lost its cutting edge technological supremacy after 30 years of
28 subsidies.
29

30 On the eve of World War 1 Germany produced only 2.7 M ton sugar, and the drain of
31 workers from agriculture to the trenches from 1914 to 1918 spelt catastrophe for all the
32 Central Powers and for Russia. French sugar was grown and processed in the belt of
33 Northern France which was wrecked during the fighting on the Western Front. Thus in
34 the harvest of 1919 Germany produced only 742000 ton beet sugar [11], and the picture
35 was as bleak for the other belligerents of the World War. Neutral nations such as
36 Denmark, Holland and Sweden could profit from the demise of the large European sugar
37 producers, but the primary beneficiaries were the overseas producers. While beet sugar
38 production decreased from 8.75 M tons in 1914 to 3.6 M tons in 1919 cane sugar
39 increased from 9.8 M tons to 12.2 M tons in 1919 [11]. Cuba, Brazil, Peru, India, Dutch
40 East India, Australia (Queensland), South Africa, and small islands in the Indian Ocean
41 (Mauritius) and in the Pacific (Fiji) led the resurgence of cane sugar production.
42 The World Crisis of the 1930's hit all Western economies. Attempts by the Nazi regime
43 to revive the German sugar industry mostly failed [8], and US beet (and cane) sugar
44 industry was almost suffocated by importation of cheap sugar from the American
45 financed "sphere of influence" in the Caribbean and on mainland Latin America [12
46 p.742]. Danish sugar industry was saved by a far sighted government policy that
47 guaranteed sugar growers a reasonable income even during the hardships of the 1930's
48 and yet gave a small, but adequate margin for the shareholders of DDS. The sugar
49
50
51
52
53

54 ² Unfortunately this key reference to the establishment and early growth of the
55 Danish sugar industry (DDS) is not translated. It is rich in detail and pictures and
56 authored by people who participated during the first, difficult period.
57
58
59
60

1
2
3 factories were allowed to keep 1/3 of all profit derived from reduction of production
4 costs. This prepared the way for accumulation of capital in the industry, and the technical
5 know-how accumulated in DDS was the key to the expansion of Danish sugar technology
6 to the rest of the world after 1950.

7
8 When peace came to Europe in 1945 it found the sugar industry crippled once more,
9 especially in Germany which had lost a large portion of its sugar growing areas to
10 Poland, and where the resuscitated sugar industry of DDR remained undercapitalized and
11 inefficient, also after the reunification of Germany in 1991.

12
13 Towards the end of the 20th century the global sugar production reached an astonishing
14 130 M tons per year from a level of about 20 M tons in 1920. The population increase in
15 the Third World (India, China and Brazil) and increasing *per capita* sugar consumption
16 were the obvious reasons. The main producers were, however, not the same as those of
17 the early 20th century. Brazil and India, each with 18 million tons were the leading
18 producers. China with 8 million tons was an emerging giant, and the European Union
19 with a production slightly below 18 million tons fought to keep its position. The US
20 produced less than China and had to import sugar [13].

21
22 The reason for the dramatic resurgence of cane sugar is threefold: The cost of land for
23 sugar growth is small in the big tropical countries, the obtainable yield of sugar per ha is
24 higher and the growth season longer, and finally the cost of labor is much smaller. The
25 full advantage of sugar cane cultivation was obtained by heavy capitalization of the
26 tropical sugar industry and by transfer of all the technological improvements achieved in
27 150 years of European beet sugar production. The only exception is Cuba with an
28 illustrious history of profitable sugar production since the mid 19th century, and a world
29 leader in sugar export before the revolution in 1959. Its attempt to increase the annual
30 sugar production to 10 M tons in the nationalized sugar industry failed abysmally [14]
31 despite a massive, loan-financed capital injection after 1962. Since the trade agreements
32 with the USSR were abolished after 1991 Cuban sugar has fought to survive at a level of
33 about 4 M tons per year.

34
35 Sugar production in the second half of the 20th century has not only seen competition
36 between beet and cane sugar. Since World War 2 artificial sweeteners have gained some
37 popularity (especially with diabetes patients) despite the questionable health issue of
38 ingesting organic chemicals instead of a “natural product”, sugar. Especially aspartame,
39 cyclamates and sorbitol have obtained about 15 % of the market share for sweeteners
40 since their introduction in the 1960’s. They are supposedly risk free compared to
41 saccharine, and they appeal to the present day “less-sugar” philosophy.

42
43 Of much more serious consequence to the sugar industry is the development of
44 “isoglucose” (a term used by the EU) by liquefaction of corn starch (HFCS, High
45 Fructose Corn Syrup). In 2006 HFCS is on a par with sucrose in the US [6] and covers a
46 third of the sugar consumption in Japan, Korea and Canada. In Europe production of and
47 use of HFCS for soft drinks and in the bakery has until now been modest with an annual
48 quota of 300 000 tons, but it may increase as a result of the drastic decline of the EU
49 sugar subsidies after 2007-unless, of course, the price of grain increases immoderately
50 due to the lingering food crisis.

51
52 From the start the European Common Market subsidized European agriculture, and in
53 particular the sugar industry with import duties and even with export bounties that
54 amounted to a light version of the sugar regime before the Brussels agreement of 1902.
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

A quota system by which each member state of the EU was allowed to produce a certain amount of sugar at guaranteed sales price was instituted in 1968 and continued basically unchanged until 2006. “A fair income for EU producers and self-sufficiency” [6] was the guiding principle. There was an A-quota, determined by an estimate of domestic consumption, and a B-quota aimed at export opportunities. From 1993 to 2007 the guaranteed minimum price to growers was 46.72 and 32.42 € per ton beet used to produce respectively A and B quota sugar. The “intervention”, *i.e.* guaranteed minimum price to producers, was 631.9 and 523.7 € per ton for white and “raw” sugar respectively. Although the net sugar export from the EU (2.8 M tons in 2004/5) is minute in comparison with an export from Brazil of more than 11 M tons, the subsidy by a domestic price 3 times higher than the world market price has long been untenable. In 2005 a case was brought to the WTO by Brazil, Australia and Thailand. A WTO panel ruled that the so called C sugar exports at world market price was in fact subsidized by revenues from production under A and B quotas while sugar from third party countries was denied access through import duties.

This is the background for the new sugar regime in the EU. The A and B quota sugar distinction disappears, and over a 4 year period from 2007/8 to 2010/11 the intervention price for both white and raw sugar is lowered by 36 % to 404 € /ton for white sugar, and the price to growers will decrease to 26 € /ton beet. At the same time the preferential treatment of sugar import from the former colonial empires in Africa, the Caribbean and the Pacific (ACP countries) is abolished, and import duties from third party countries are significantly lowered.

The immediate effect has been in the ACP countries. Thus, since 2007 sugar production has ceased in Trinidad and Tobago, a traumatic experience for a nation that had “cane is my life” as its motto. Luckily in Trinidad and Tobago the oil and gas industry has long since replaced sugar as a major source of national income, but Jamaica and the French islands have nothing to replace sugar except the uncertain tourist industry.

The repercussions for the 325000 sugar growers in the EU are also significant, and with subsidies from the EU the growers have to reduce the cultivation area. Since the late 1980’s the sugar producers have prepared for an inevitable change by consolidating their positions, basically by acquiring sugar quotas from less efficient countries in the EU. The case of Denmark is typical: In 1989 DDS bought the single Danish coop-sugar factory, and within a few years *Danisco*, the successor company to DDS, bought Swedish and Finnish sugar, and had acquired the derelict sugar production in Mecklenburg-Vorpommern. The 8 factories of this *Bundesland* were reduced to one, state-of-the-art factory in Anklam where the capacity has increased from 3000 to more than 10000 t sliced sugar beets per day. With a later acquisition of Lithuanian sugar *Danisco* produced 1 M ton sugar in 2007, more than twice the sugar quota 391000 t for Denmark. Finally, in July of 2008 *Nordzucker* in Germany bought the sugar division of *Danisco*, a clear sign that consolidation of European sugar production is still in progress.

The turbulence in the sugar industry exemplifies a revolution of the whole agricultural sector. The position of “sugar” in the 21st century and the opportunities that are unfolding for the best of the traditional sugar producing companies naturally relies on strategic corporate decisions, but the fund of technical and scientific knowledge accumulated in the sugar companies is the foundation on which success will grow.

1
2
3 Some of the technological developments that came from the sugar industry through the
4 past centuries will be reviewed below. In particular the entrepreneurship of the sugar
5 industry will be a strong asset when sugar joins with the fermentation industry to take a
6 leading role in a future that is much less dependent on oil.
7
8

9 10 The legacy of the sugar industry to the world of tomorrow

11
12 With an annual sugar production hovering around 160 million tons the global sugar
13 industry is certainly not in recession. The European share in the global production will
14 continue to decrease, but as discussed in the previous section there has been enough time
15 for the beet sugar producers to change their focus. The foremost asset of the sugar
16 industry is now its high technological standard, a standard that has been continuously
17 improved through 170 years of sharp competition.
18

19 The historical contribution of the sugar industry is that it fundamentally changed rural
20 life. Large sugar factories emerged in small country towns, and they employed thousands
21 of workers who might eventually use their experience to establish new industries. Roads
22 and railways contributed to improved communications in rural areas which experienced a
23 rapid accumulation of capital and an improved status on the national scene.
24

25 It was on the large acreage farms owned by well educated, progressive farmers that the
26 economic benefits of sugar production were reaped. The social structure in the
27 democratic countries of Northern Europe did, however, prevent the formation of a class
28 of impoverished rural workers, and cooperatives could sometimes compete on equal
29 terms with public companies backed by large financial institutions.
30

31 This was, and perhaps still is, the fundamental difference between European sugar
32 producers and cane sugar producers in India, in Cuba or Brazil where absentee owners
33 from the US or Europe did not encourage local participation at a level higher than measly
34 paid unskilled work. Sugar cane growth gave subsistence living for thousands, but the
35 trickle-down effect of the wealth generated to the owners materialized at a snails pace.
36 Unions were not fighting for the rights of workers, and the misery of migratory workers
37 exploded in frequent and bloody riots. During the first 80 to 100 years of European sugar
38 production, the situation was of course not much better, and migratory workers from
39 especially Poland flocked to till the fields for cultivation of sugar beets and to do the
40 arduous work of weeding the rows of beet plants. Still, European (and North American)
41 science contributed significantly to lessen the toil of sugar production.
42

43 The sugar beet naturally produces a multiple-germ seed ball which results in several
44 seedlings emerging from one seed ball. Removing all but one seedling from a plant in
45 order to get one large, healthy beet drastically reduced the cost of labor in the field and
46 gradually made the intolerable use of underpaid workers obsolete.
47

48 In the US and in several European countries intensive research programs were carried out
49 to produce single germ seeds. Since the early 1940's mono-germ seeds (discovered by
50 two Russian plant scientist, Dr and Mrs V.F. Savitsky who worked in the US), combined
51 with mechanical seed planting are milestones in this progress. Other agricultural
52 scientific programs such as the production since 1950 of polyploid seeds by *Maribo*
53 *Seeds*, a subsidiary of DDS, have led to beets with high sugar content (18-20%), larger
54 beet yield per ha (up to 50 tons/ha), and also to beets with resistance to a number of plant
55 infections.
56
57
58
59
60

1
2
3 One could have hoped that the *Round-up* resistant sugar beets, first successfully used in
4 pilot scale by *Maribo Seeds* during the 1980's, would have been met with political
5 acceptance in Europe. The total use of herbicides is diminished, the plant protection and
6 fertilizer programs are optimized, and relatively innocuous chemicals can be used. Plant
7 growers in the US and elsewhere appear to have obtained significant advantages by GMO
8 techniques, also in the cultivation of sugar.
9

10 The huge efforts of agricultural scientists to improve the value of the crop have run in
11 parallel with efforts to improve the productivity and yield in the sugar factories.

12 In the highly competitive environment of the mid-19th century where beet sugar
13 producers fought, not only amongst themselves but also with large cane sugar producers
14 such as Cuba, a number of immensely useful inventions were made.
15

16 The open pan evaporation that preceded crystallization of sugar had a history dating back
17 to the Antioquity. The high temperatures used, and the almost complete lack of process
18 control led to vast losses in white sugar, and the cost of wood rose unacceptably, even to
19 the point of bankrupting some of the almost denuded tropical sugar islands.. Also of
20 course, open-pan evaporation was decidedly unhealthy for the workers who stirred the
21 broth in a foul smelling environment.
22

23 The closed, steam heated pan evaporators working under partial vacuum were first
24 developed in the sugar industry around 1810, and by 1850 vacuum pans were widely
25 used. The first patent on a multi-effect evaporator system in which steam from the first
26 stage is used at a lower pressure to evaporate almost the same amount of water in the next
27 stage, was granted in 1846 to a French-American engineer, Norbert Rillieux [16].
28

29 The sugar industry contributed heavily to the development of industrial centrifuges in the
30 1880's, hereby reducing the time to collect sugar crystals from the viscous supernatant
31 from hours to minutes. A number of patents originating from the sugar industry for
32 filtration equipment demonstrate the role that sugar played for another key unit-operation
33 in chemical and biochemical industry. Add to these specific pieces of equipment all the
34 inventions made for transportation of beets in the factory and for cutting up the beets in
35 regular sized slices that could withstand the extraction process and at the same time
36 permit almost complete extraction of the sugar. Finally, numerous inventions in cost
37 effective heat exchangers and evaporators, an early and detailed application of in-depth
38 process monitoring, process control and process optimization, and scores of ingenious
39 inventions that could give small, but still significant improvements in the large scale.
40
41
42

43 Most of these inventions were made in the beet sugar industry, first in Europe and
44 somewhat later, but often greatly improved in the US. Cane sugar inherited these
45 technological advances during the 20th century and, combined with favorable growth
46 conditions, and with what some people claim to be access to "unlimited new growth
47 areas", the road towards dominance of the cane sugar industry is free.
48

49 The progress in sugar chemistry, biotechnology and in mechanical skills is evident from
50 the thousands of scientific papers and monographs that have been published, often by
51 people who worked in the industry and who patiently struggled to improve the processes
52 for which they were responsible.
53

54 Two examples will be given of individuals who made lasting contributions both to the
55 sugar industry and to the engineering sciences in general. The examples are taken from
56
57
58
59
60

1
2
3 the Danish sugar industry, but certainly the examples could also have been taken from
4 any of the other front-runners in the sugar industry.

5
6 In 1940 the DDS engineer A. Brieghel-Müller gave the theoretical background of the
7 lime treatment of raw sugar juice in his doctoral thesis [17]. Raw juice contains invert-
8 sugar (glucose + fructose), amino acids, proteins and other N-containing compounds that
9 will give rise to discoloration of the final sugar. Polysaccharides (pectin from frost
10 damaged beets) will lead to severe filtration problems. "Liming", *i.e.* the treatment of the
11 juice with $\text{Ca}(\text{OH})_2$, will eliminate many of the impurities as coagulates. But due to the
12 complicated nature of the juice, liming is not just one process, but it consists a series of
13 steps: Pre-liming, main liming, saturation with CO_2 etc. The process has been studied, at
14 least since the 1870's, and a catalogue can be compiled of many hundred juice
15 purification methods, often one for each factory. Brieghel-Müller's contribution was that
16 he provided the chemical and physical-chemical foundation for the empirically derived
17 recipes. As a life-long employee at DDS he materially contributed to make Danish sugar
18 the purest sugar on the market, with little loss of either quantity or quality.

19
20 10 years later another DDS engineer, Henning Brünniche-Olsen, was granted patent on
21 the horizontal sugar extractor [18] that revolutionized the sugar industry. When cane is
22 milled in the classical way a very large fraction of the sugar remains in the bagasse. Beets
23 cannot be milled at all. Hence batch extraction, and later continuous extraction of sugar
24 was developed in the beet sugar industry. Brünniche-Olsens invention perfected the
25 continuous, counter current extraction of sugar from beet slices (cosettes). The
26 complicated, but robust machinery is able to displace 97 wt % of the sugar in the beet
27 with the same amount of water, giving an extract to the evaporators with about 14 wt %
28 sugar, *i.e.* a mass flow that is only about 25 wt % higher than the beet treated in the
29 extractor.

30
31 The DDS-extractor was an immediate commercial success. Its very high yield of sugar
32 and very low energy cost (high initial sugar concentration in the juice) made it the
33 extractor of choice in about 50 % of sugar factories world-wide. Variants of the
34 continuous extractor, such as a vertical extractor (more complicated, but with a capacity
35 of 10000 t beet per day compared with 3500 t per day for the standard DDS extractor)
36 were also marketed, and in a period from about 1955 to 1980 engineers from DDS were
37 retrofitting sugar factories all over the world, for cane as well as for beet sugar. In an
38 attempt to combine sugar production with cultivation of other farm products a mini-sugar
39 factory (300 t /day) with a DDS extractor was developed for small scale cane sugar
40 production in Third World Countries. It was delivered in crates at the site, ready for
41 immediate assembly, a remarkably simple solution for *e.g.* rural districts in Tanzania.

42
43 As was the case with Brieghel-Müller's work, the DDS encouraged publication both of
44 the scientific background of the invention and of many technical details of the DDS
45 extractor. The doctoral thesis of Brünniche-Olsen [19] is an early example of a mature
46 application of Transport Phenomena and Mathematical Modeling in Biochemical
47 Engineering. A series of extraction experiments on cosettes give the parameters for a
48 PDE model of the extractor, and the results are applied to design of full scale extractors.
49 Several manuals or textbooks on sugar technology were later published by DDS [20],
50 most of them authored by the CSO, Dr Rud Frik-Madsen, inventor of an UF/RO system
51 that developed into a division of DDS. A remarkable feature of these books is that they
52
53
54
55
56
57
58
59
60

1
2
3 freely discuss, also less successful DDS technologies, and give rather detailed advice on
4 how improvements have been made or should be made. This publication activity of a
5 major industrial company suggests that the company has total faith in the superiority of
6 its approach. It is willing to share its current knowledge with other sugar producers, and
7 perhaps through a demonstration of technological strength obtain further contracts for
8 transfer of knowledge.
9

10 It is the *preparedness* for change that is the conclusion drawn from the technical
11 examples discussed above. The sugar industry is ready to enter other fields, not
12 necessarily based on sugar grown and produced domestically, but based on the
13 accumulated *knowledge* within the industry.
14

15 The whole adventure of bio-fuels started in the sugar industry. The technical expertise
16 required to run a sugar factory profitably was seamlessly transferred to another large
17 scale production, ethanol by fermentation. Behind the smoke-screen of politically
18 motivated subsidies to the bio-ethanol industry one finds a true story of massive cuts in
19 production costs that may *really* make bio-ethanol cheaper than oil-based transportation
20 fuels. The sugar companies have not only understood to design and operate the
21 fermentation/downstream processes, but they have also embraced the technologies of
22 Molecular Biology. Thereby the vital upstream design of a yeast or a bacterial strain to
23 give both a high selectivity for the desired product and a high productivity per unit capital
24 are considered on a par with the fermentation and the downstream processes.
25

26 The highest potential for application of this fund of knowledge may not necessarily be in
27 the food industries where regulations will hamper the use of GMO, at least in some parts
28 of the world. The “old” chemical industry could be the most natural partner for a “new”
29 sugar industry. Here the successful outcome of the co-operation between DuPont,
30 Genencor and Tate & Lyle to produce, since 2006/7, 45000 tons/year of the intermediate
31 1,3-propane diol for the new polyester *Sorona*® has probably opened up for many
32 similar alliances. The polylactic acid polymer production of Cargill is another example of
33 a sugar based agro-company that has invested heavily in traditional chemical industry.
34 The 2008 alliance between DuPont and Danisco [21] by which the two companies will
35 invest heavily in the race to develop a commercially attractive second generation bio-
36 ethanol production is made possible by the acquisition of Genencor by Danisco in 2005.
37 Together the two partners possess expertise in all the fields needed for success: Chemical
38 Process Technology, Food and Ingredients production, and finally in Modern Biology.
39 They wish to establish *production* of bio-ethanol, not just develop an enzyme based
40 process route. At the end of the day this might prove a better strategy than that of other
41 companies which (perhaps out of necessity because they lack the financial strength)
42 prefer to sell or license individual processes to a final producer of the commodity.
43 Very recently [22] another alliance was announced, this time between Danisco and
44 Goodyear. The goal is to produce poly-isoprene for the tire and rubber industry.
45 The press release states that by 2013 the two companies will have an industrial process to
46 produce bio-based isoprene as an alternative to petroleum-based production of this key
47 compound for the rubber industry.
48

49 As strange as it may seem to a layman that one can produce “tires by a fermentation
50 process” the biochemical role of isoprene (2-methyl-1,3-butadiene) in cells is of course
51 well known. The companies are at the present mute about their process which is probably
52 still in the process of being patented, but one may reasonably assume that the mevalonate
53
54
55
56
57
58
59
60

1
2
3 pathway has been amplified, and that one of the intermediates such as isopentenyl-
4 pyrophosphate is being polymerized to the desired polymer, 4-poly-isoprene. This would
5 be analogous to the mechanism by which high molecular weight hyaluronic acid is
6 synthesized and excreted by bacteria.
7
8

9 Conclusion

10
11 At the entry to the 21st century the sugar industry appears to have a bright, but unforeseen
12 future which is not necessarily based on producing sugar, but rather on the application of
13 its accumulated technological base, pared with acquisition of new expertise in
14 Biotechnology. The Biorefinery is a highly publicized synonym for all the commodity
15 products that can be made from carbohydrates. Bio-fuels can and will eventually be made
16 from cheap lignocellulosic biomass, but for the more sensitive and higher value added
17 products such as polymers sugar is the right raw material since the risk of incurring high
18 downstream costs are significantly lower than from a complex raw material.
19 Here is the challenge and the opportunity for the sugar industry all over the world.
20
21
22
23
24
25
26
27

28 References

- 29
30 [1] Williams E., *From Columbus to Castro. The history of the Caribbean*, André
31 Deutsch, 1970 (paperback edition, 2003).
32
33 [2] Hansen T, *Slavernes kyst* (1967), *Slavernes øer* (1970), *Slavernes skibe*
34 (1971), Gyldendal, Copenhagen . The famous trilogy of the Danish West Indies is
35 translated into English by Karl Dako, *Coast of Slaves* (2002), *Islands of Slaves*
36 (2005) and *Ships of Slaves* (2003), Sub-Saharan Publishers, Accra, Ghana.
37
38 [3] Nyerup R, *Kjøbenhavns Beskriivelse*, Prost and Storch, Kjøbenhavn, 1800.
39
40 [4] Achard F.K, *Der neueste deutsche Stellvertreter des indischen Zucker, oder der*
41 *Zucker aus Runkelrüben-der wichtigste und wohlthätigste Entdeckung des 18.*
42 *Jahrhundert*, Berlin, 1799. New and embellished edition: *Die europäische Zucker*
43 *fabrikation aus Runkelrüben, des Rums, des Essigs und einer Coffes Surrogat aus*
44 *ihren Abfällen*, J. C. Hinriches, Leipzig, 1809- perhaps the first reference to the
45 economic benefits from the byproducts of sugar production.
46
47
48
49 [5] Anon, *History of the company Erdania Béghin-Say*. In *International Directory of*
50 *Company Histories* Vol 36 p.185-188, St James Press (Chicago, Ill), 2001.
51
52
53 [6] *The European Sugar Sector*, ed. M.F.Boel (Commissioner for Agriculture),
54 European Commission, 2006.
55
56
57 [7] Wallbaum U, *Die Rübenzuckerindustrie in Hannover: Zur Entstehung und*
58
59
60

1
2
3
4
5
6
7
Entwicklung eines landwirtschaftlich gebundene Industriezweigs von den Anfängen bis zum Beginn des Ersten Weltkriegs, *Beiträge zur Wirtschafts- und Sozialgeschichte*, n° 83, Franz Steiner (Stuttgart), 1998.

- 8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
- [8] Vascik G.S, Sugar Barons and Bureaucrats: Unravelling the relationship between economic interest and government in modern Germany 1799-1945, *Business and Economic History*, 2nd series, Vol. 21, p. 336-342, 1992.
- [9] *New York Times*, November 24, 1901.
- [10] Drachmann P. and Estrup L., *Aktieselskabet De Danske Sukkerfabrikker 1872-1922*, Egmont Petersen (København), 1922.
- [11] *New York Times*, May 2, 1920.
The article is based on a paper by T.Zeller printed in *Deutsche Industrie- und Handelszeitung*, March, 1920.
- [12] Mc Ginnis R.A., *Beet Sugar Technology*, published by the Beet Sugar Foundation 2nd ed., 1971.
- [13] Zimmermann B and Zeddies J, International competitiveness in the sugar production, 13th International Farm Management Congress Wageningen (Holland), 7-12 July 2002. (Unpublished, but available on the Internet).
- [14] Hagelberg G.B and Alvarez J, *Historical overview of Cuba´s cost of sugar production: Implications for the future*, Document FE 629 published by Institute for Food and Agricultural Sciences, University of Florida, Gainesville FL, 2006.
- [15] Batista P. Nogueira, Política tarifária britânica e evolução das exportações brasileiras na primeira metade do século XIX, *Revista Brasileira de Economia*, 34, 203-239, 1980.
- [16] US patent N° 4879 “Evaporating Pan” to N.Rillieux; dated December 10, 1846.
- [17] Brieghel-Müller A., *Über Filtrationsuntersuchungen*, Doctoral dissertation, DTU (1940)
- [18] *An apparatus for continuously mixing together a liquid and one or more substances*, GB patent N° 674.794 to *De Danske Sukkerfabrikker*, (July 2, 1952).
- [19] Brünniche-Olsen H., *Solid-Liquid Extraction*, Doctoral dissertation, DTU (1962).
- [20] (Anon., but the principal author is R.Frik-Madsen) *Om sukker og sukkerfabrikation hos DDS*, (1985), *Tekniske erfaringer og finesser i DDS* (1994), *Sukkerproduktion* (1997). by *De Danske Sukkerfabrikker*.

1
2
3
4 [21] Danisco, *Annual report 2007/8*, Copenhagen, May 2008.
5
6

7 [22] Danisco, (and Genencor) press release, September 16/17, 2008.
8
9

10 11 12 13 14 Figure captions 15

16 17 Figure 1

18 “Kort over Eylandet S^t Croix udi Amerika” (“Map of the island of S^t Croix in America”)
19 Copenhagen 1754 (Royal Library, Copenhagen 4340111-0-1754/3). Reproduced with
20 permission.
21

22 The intense sugar cultivation [2] on this small (212 km²) island in the Danish West Indies
23 is clearly seen from the figure. Fredrichstead and Christianstead are now tourist
24 attractions in the American Virgin Islands. Sugar cultivation ceased many years ago.
25

26 27 Figure 2

28 The first manual of sugar beet production, [4].

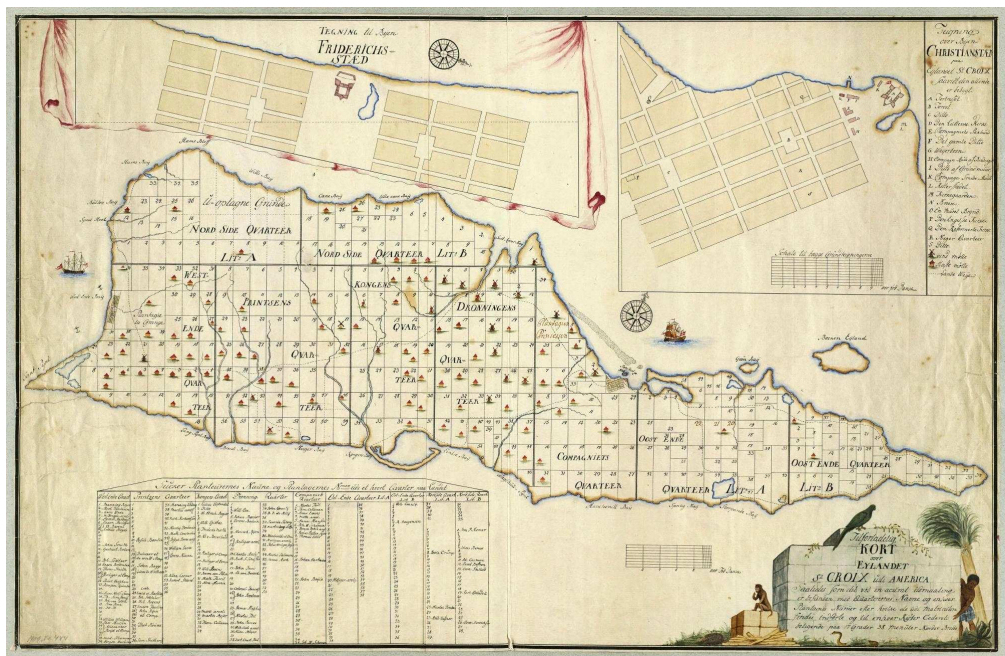
29 The title translates to “The newest substitute for (West) Indian sugar, or sugar from beets-
30 the most important discovery of the 18th century”

31 Royal Library, Copenhagen. Reproduced with permission.
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



264x226mm (96 x 96 DPI)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



529x343mm (96 x 96 DPI)

Review