TECHNOSCIENCE, MODERNITY, AND THE STATE

The Limits of Chemical Control in the Caribbean Sugar Factory

David Roth Singerman

"All the Sugars of the World, If They Are Pure, Are Worth the Same"

Looking back in 1940, the Cuban sociologist Fernando Ortiz juxtaposed the properties of tobacco and sugar to understand Cuban history. Ortiz explicitly connected the natural origins, material characteristics, and means of production of each commodity to its divergent personality as a historical actor. While the tobacco leaf was rolled and smoked intact, sugar was homogenous, "made by man and power."[1] Sugar was the crop of world capitalism, of international corporations that owned huge factories and through them controlled the destiny of the Caribbean. Cigar rollers' famous radicalism was inverted in the subservience of sugar-mill workers, who toiled at their monotonous tasks in noise and heat.

These conformist properties of the sugar world emerged because, Ortiz argued, unlike tobacco, all sugar was fundamentally indistinguishable. "For both sugar-grower and refiner the aim is the most," he wrote,

> the most cane, the most juice, the most bagasse, the most evaporating-pans, the most centrifugals, the highest crystallization, the most sacks, and the most indifference as to quality for the sake of coming close as possible in the refineries to a symbolic hundred per cent chemical purity where all difference of class and origin is obliterated, and where the mother beet and the mother cane are forgotten in the equal whiteness of their offspring because of the

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equal chemical and economic standing of all the sugars of the world, which, if they are pure, sweeten, nourish, and are worth the same.[2]

Pure sugar was just a chemical; the function of a sugar mill was not to transform sugar but to restore it to that chemical essence. Ortiz even read the factories hulking over Caribbean landscapes back into the sugar cane plant itself, as extensions of the "little natural sugar mills of the cane stalks" themselves. Thus Ortiz presented as natural—even inevitable—the reduction of the "botanical mass" of the fibrous and juicy sugar cane, composed of a variety of substances and flavors, into crystals of something called sucrose. It was this crystalline identity that gave sugar its fetishistic commodity status. As sucrose, sugar could "pass for white, travel all over the world, reach all mouths, and bring a better price," having become as close to an ideal universal commodity as any actual object could be.[3]

For Ortiz, and for later historians, the fact that the food called sugar is fundamentally a molecule—$C_{12}H_{22}O_{11}$—helps explain the consolidation of foreign capital's control over the means of its production. But the idea of sugar's chemical identity was a product of the power of capital too. In writing of the mechanization of sugar factories, historians have ignored the skill of human beings who worked within them. Yet only their skill at extracting sugar from plants made it appear inevitable that all the sugars of the world were the same.

The sugar mills of Ortiz's Cuba emerged during the last decades of the nineteenth century and the early decades of the twentieth. If the first "sugar revolution" brought the sugar plantation to the Caribbean in the seventeenth century, the planters, financiers, engineers, and chemists of the late nineteenth century spoke equally reverently of their own age.[4] In 1926 the Bostonian sugar magnate Edwin F. Atkins recalled that his six decades in business "have seen such a revolution in the production and manufacture of sugar . . . as probably, in a like term, will never be repeated."[5] Responding to the subsidized and protected beet-sugar manufacturers of Europe, the sugar cane processors of Atkins's second revolution had replaced the traditional mill and plantation estate, built on enslaved labor, with great steam-driven factories that matched their beet-sugar brethren in technical sophistication. Atkins recalled that "almost every year, some new machinery was installed at Soledad," his own factory.[6] As these enterprises grew in scale, and as cane culture itself was reorganized to feed them, they became known as "central factories," or *ingenios centrales*. Scholars have affirmed Atkins's judgment and have begun to place the changes to the sugar economy within the context of a much broader "second industrial revolution" that reshaped the production of everything from steel to dyestuffs.[7]

The great Cuban historian Manuel Moreno Fraginals argued that "as regards sugar in the Caribbean, in the nineties everything was completely different from what existed in the sixties." He presented the craftsman sugar master of the plantation as an archaic figure, "guided only by his senses (smell, taste, touch, hearing), by his long experience, and by orally transmitted tradition." Against that he contrasted the "standard" operations of the centrals, "supervised by technically trained professionals, who were aided by internationally recognized analytical methods carried out on modern laboratory equipment."[8] Atkins, for his part, made sure to credit Wilfrid Skaife, a Canadian chemist who acted as his trustworthy deputy. Skaife "took charge of the sugar house," Atkins recalled, and "was full of new ideas" for improving it.[9] The crystals that emerged from the mechanized factories, according to Moreno Fraginals, "were as different from the previous product as the central was different from the old slave-run ingenio."[10] The clearest evidence of the second revolution in sugar was the chemical sameness of sugar itself. That sameness was newly extractable by the centrals, yet has been presumed to be inherent in sugar's nature.

Scholars of science studies have long known how to interpret such claims to sameness and lack of differentiation: through the study of metrology, the social work that turns the products of specific sites and their localized techniques into seemingly natural or self-evident ways of dividing up the world.[11] Yet with a few salutary exceptions, recent histories of commodities and capitalism have not subjected their metrologies to critical reflection. While they recognize that standards for grading or classification are essential to making a market in a commodity, such histories continue to accept the universality of standards imposed from positions of power.[12]

The lack of metrological understanding is especially pernicious because capitalism has been largely defined through struggles over metrology, of contests over the legitimacy of different means for valuing the products of nature. These struggles have defined some of capitalism's most iconic sites, from seventeenth-century gold markets and eighteenth-century tobacco docks to nineteenth-century coalfields and twentieth-century oil refineries.[13]

In the following pages I hope to begin to show that the industrial sugar factories of the late nineteenth century were a site of metrological conflict just like the exemplary sites of capitalism identified above. Skillful human work in those factories persisted long after most observers have supposed otherwise. More importantly, that skill was irrevocably embedded within fundamental features of industrial sugar making. Cuba and Puerto Rico are the focus of this essay, since they were the largest Caribbean components of what April Merleaux has recently called the US sugar empire. These islands, along with the Dominican Republic, were dominated by US capital and produced most of their sugar for the US market. They were linked to other sugar-producing regions in this empire not necessarily through direct political or military rule from Washington but through tariffs, quotas, subsidies, and other trade policies.[14] They also pioneered the huge central factory that became a recognizable institution across the Caribbean and the world.[15]

Those studying the political economy of sugar have recognized that the institutions of its production defy analysis through national or insular categories.[16] By the late nineteenth century, the people who operated these factories came from across the globe. "Our manager is an American," Atkins wrote to one candidate for the job of chemist, "the chief engineer Scotch, the pan men are Germans, laborers in sugar house mostly Chinamen."[17] Engineers, managers, and chemists rarely stayed put, but might spend half the year in beet fields and half in cane factories or alternate between academic employment and factory superintendence.[18] They read handbooks and publications boasting global lists of contributors and subscribers. The heavy machinery for factories in Spanish-ruled Cuba and Puerto Rico came from Britain, France, and the United States.

The invocation of that machinery has heretofore hidden the two kinds of invisible skilled labor that made sugar appear to be a chemical commodity. The first form is that of the sugar makers who worked in factories like Soledad. The sweltering, noisy, open-kettle sugar-boiling houses of the seventeenth, eighteenth, and early nineteenth centuries depended on the nous of enslaved artisans in well-documented ways. This dependence was so fundamental that even their own enslavers themselves could not ignore it. These skills are supposed to have been obviated and rendered unnecessary by the sophisticated, chemically controlled industrial processes of the sugar mill but in fact remained crucial to the success of the central.[19]

The second form is the labor of chemists like Skaife. In historical scholarship on central sugar factories, the presence of chemists has largely been an index of sophistication, "a transition stage in the modernization of the industry" showing that owners and managers understood the need for scientific knowledge.[20] More recently, scholars have emphasized that chemists, botanists, and other Caribbean scientists constructed "hybrid" or "creole" forms of knowledge—and, as efforts to write global histories of science have reminded us, all science is really creole and hybrid.[21] Therefore, accepting the notion of sugar as a globally uniform chemical commodity has meant ignoring the activity of the people responsible for creating that uniformity. As a result, the "revolutionary" industrial factory is reduced to the culmination of centuries of development toward efficient technical perfection. For if pure sugar is sucrose, then chemists exist merely to ratify this perfection, and once they do, they become invisible. On the one hand, chemists' rhetorical, intellectual, and physical labor rendered the role of the sugar artisan invisible. On the other hand, the more that chemists' expertise made chemical purity the standard measure of value, the more peripheral and obscure the work of chemists themselves became.

Skilled Labor in the *Ingenio,* Machines in the Central

The erasure of skilled labor in descriptions of the central factory stands in stark contrast to the sugar plantations of the sixteenth through the early nineteenth centuries. These are portrayed as sites of artisan skill, technical know-how, and technological progress.[22]

The principle on which the plantations were organized was sensitivity to time: within a few hours of cutting, the juice had to be extracted from the canes, lest it ferment, and soon after extraction the juice had to be boiled.[23] This biological clock that dictated both the size and configuration of the plantation as an agricultural-industrial unit and the organization and discipline of the sugar mill itself.[24] Once slaves had carted the cut cane to the mill house, others fed the shoots through the rollers of the wind-, animal-, or water-powered mill itself. As the cane was crushed, the juice flowed through pipes to the boiling house. The smashed canes, known as bagasse, still contained a large portion of juice, so in order for them to be used later as fuel they were carried into the sun and left to dry. The centerpiece of the boiling house was a series of increasingly small kettles, called coppers or taches, in which the juice was successively heated and cooled. As various particulates and other substances floated to the top, they were skimmed off so as not to impede crystallization or give undesirable flavors.

The art and skill of sugar boiling lay in reducing the liquid in the open kettles without burning the sugar itself. In plantations that used the so-called Jamaica train, in which all coppers were built into the same unit of brickwork and heated by the same furnace, the temperature was "controlled by yells" from the slave at the kettle to the furnace-minder.[25] From copper to copper, slaves carried the thickening syrup. Finally, in the smallest kettle, the sugar master manipulated the heat and additives to bring the solution to the point where crystals began to form. Then he made his "strike"—removed the syrup from the heat and transferred it to troughs, where as it cooled it was beaten with wooden paddles as encouragement to crystallize further.

Knowing when this crystallization point had been reached was perhaps the sugar master's most coveted ability. In 1765 the Antiguan planter Samuel Martin complained that the "art of boiling sugar [is] generally least understood either by overseers or their masters; but . . . trusted wholly to the skill of negro-boilers, who indeed arrive by long habit to some degree of judgment by the eye only."[26] It required more than sight: the sugar master stretched the scalding syrup between his fingers to test its elasticity, tasted it, inhaled its odors, and listened for its crackle. After the troughs, the cooling semicrystalline mass was poured into great inverted conical molds. Over several weeks, the molasses, thick sweet liquid from which crystals could no longer be coaxed, drained out through the bottom and into troughs that collected it for future use, while the loaf itself dried in the sun. Molasses was fermented into rum, sold of its own accord, or returned to the syrup as it boiled, to extract a few more granules. The loaf could be sold whole—or, in "the most personal operation in the mill," it might be divided by the sugar master's own eye, wherever he judged a layer of one marketable quality to yield to another.[27]

In the old Ingenio La Ninfa, wrote Moreno Fraginals, the sugar master's knowledge "threw the producers into despair," and thus he was "the most slandered of all workers." As early as the 1790s, Cuban planters attempted to import graduates of European schools of chemistry. According to María Portuondo, "The new scientifically trained sugar expert was expected to inhabit the world dominated by the sugar master and bring control and predictability to the manufacturing process."[28] By the mid-nineteenth century, chemists were employed sporadically in sugar houses, as planters sought to quantify and measure production that remained in workers' hands.[29] A blank form for Cuba's *ingenio* La Ninfa, printed during the first decade of the nineteenth century, shows the information its owner demanded from thirteen divisions, including the mill, boiling house, purging house, drying room, sugar and molasses stores, and the distillery.[30]

Whatever Martin's "art of boiling sugar" included, however, it did not mean the extraction of sucrose. Such a concept could not antedate the invention of organic chemistry itself. Instead, sugar was described in other ways. So, for instance, in 1657 the Englishman Richard Ligon wrote that the sugar cane has "but one single taste," a taste that could come from the cane and nowhere else. Yet rather than speak of sugar that was "pure," he wrote that it was "white," or "well cur'd," or "of a bright colour, dry and sweet," and "of a kind of Sugar somewhat inferiour to the Muscavado; but yet will sweeten indifferently well, and some of it very well coloured."[31] Participants in the sugar economy described sugar in terms of its means of production and, above all, with the results of what Lissa Roberts calls their "sensuous" techniques of bodily experience.[32]

In fact, the claim that there was a form that could be abstracted from cane and derived from another plant arose in tandem with the claim that there was a set of practitioners called chemists and a distinct activity called chemistry. In 1747 the German apothecary Andreas Marggraf crystallized a substance from the roots of several European plants and concluded, by microscopic observation and its "strong sweet taste," that it was the same as the substance extracted from the cane: "not merely a substance approaching sugar, but in fact a true and perfect sugar, which has a complete resemblance *with the familiar sugar extracted from the sugar cane*." He published his findings as "chemical experiments made in order to extract *a true sugar from diverse plants* that grow in our countries."[33]

By the beginning of the nineteenth century, those countries that lacked reliable access to a supply of cane sugar, such as the German lands or France sans Saint-Domingue, began a desperate search for alternative sources of sweetness. Marggraf's work, commercialized with Prussian state sponsorship, brought into being an industry based on a new crop called the "sugar beet," which was capable of producing masses of sweet crystals and could be cultivated in temperate rather than tropical climates.[34] The nature of cane sugar was intimately tied to its agricultural origins. The production of sucrose, by contrast, had always depended on the chemical laboratory.

Coordinating those agricultural origins with the process of manufacture made the sugar plantation a "proto-industrial" site, but the central factory that supplanted it in the Caribbean in the mid-nineteenth century was industrial in more obvious ways (fig. 1). The usual story of changes to Caribbean sugar production in

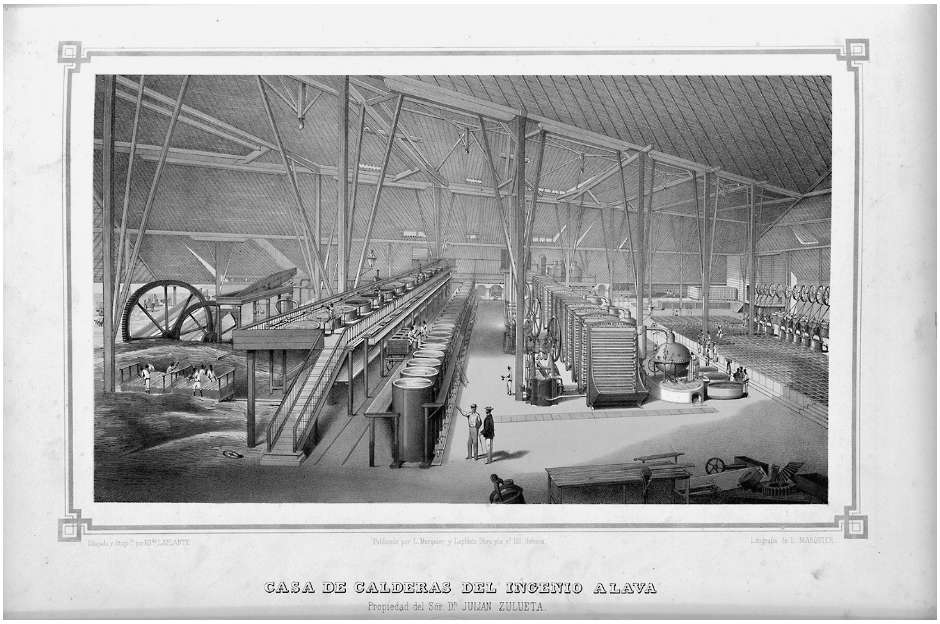


Figure 1. The boiling house of Ingenio Alava, one of Cuba's most sophisticated sugar factories in 1857. From J. G. Cantero and Eduardo Laplante, Los Ingenios: Colección de Vistas de los Principales Ingenios de Azúcar de la Isla de Cuba (La Habana: Litografía de L. Marquier, 1857), page 37. Courtesy of the Cuban Heritage Collection, the University of Miami Libraries Digital Collections.

the late nineteenth century revolves heavily around three large pieces of expensive technology: the mill, the vacuum pan, and the centrifuge.[35] As the giant steel steam mill replaced the animal-powered one, so too the depressurized "vacuum pan" rendered obsolete the train of open cauldrons. By sealing the juice from the atmosphere and lowering its pressure, the boiling point could be lowered and with it the consumption of fuel. In the 1840s these, like horizontal mills, were chained together too, in the so-called multiple effect evaporator credited to the Louisianan Norbert Rilieux. A sequence of increasingly lower-pressure chambers let the vapor from one pan boil the liquid in the next. In spite of "sound predictions of its usefulness," the vacuum pan was acquired by planters much more slowly than the steam mill, partly because of its enormous cost.[36] The final transformative device was the "centrifugal" for separating sugar crystals from molasses. Rather than leaving the wet mass to drain in conical molds, the massecuite drained from the vacuum pan to the perforated basket of a centrifuge, which spun at several thousand revolutions per minute. Centrifugals dried sugar measured in tons per hour, orders of magnitude faster than was possible under manual methods.

A number of scholars have rightly begun to recover the role skilled agents played in the process of industrializing sugar in the Spanish Caribbean. In doing so, they have joined historians of science and technology in resisting the idea that

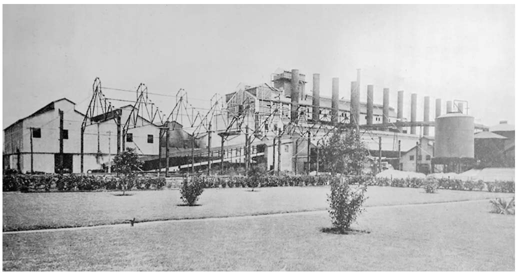


Figure 2. Central factory in Cuba, early 1900s. From Llewellyn Jones and Frederic I. Scard, The Manufacture of Cane Sugar, 2nd ed. (London: Duckworth, 1921), page 475.

machinery spreads on its own and have challenged diffusive narratives of industrialization in the sugar economy.[37] But the technologies and devices of sugar and chemistry continue to receive credit for transforming sugar itself. These devices are assigned a logic of their own and imagined to have deterministically "created larger mills and factories" that produced sugar as sucrose.[38] The capital required to purchase expensive machines meant that they could be financed only by the profits from the agricultural product of much larger catchments of cane fields, whether through outright landownership or the purchase of cane from cane farmers known as *colonos*.[39] Especially after the destructiveness of two wars in Cuba in three decades, and after American seizure of power there and in Puerto Rico in 1898, financing these giant installations was a burden that led control of the means of sugar production to shift from creole elites to syndicates of British, French, and American investors. From central-owned land or from *colonos*, expansive railroad networks fed cane to these new factories and the machines that filled them.[40] No longer integrated with the landscape, such centrals stood apart from it (fig. 2).

Centrals' sugar, in the late nineteenth century, came widely to be associated with the centrifugal, the machine that entranced contemporary observers, and whose product symbolized the efficiency of the factory itself. The poet Carlos Peñaranda, visiting Puerto Rico's first central in 1878, imagined what this "marvelous assembly of order and precision" would say to him if it could. Its machinery "combines the atoms and compresses and concentrates them with its fiery hands, and condenses the nebulae, sets them alight and converts them into suns of eternal light, which redden the vacuum to participate in the harmonious life of the universe."[41] Lay observers of the central and centrifuge linked the power of modern chemistry to the efficient operation of the machinelike sugar factory.

On the preindustrial plantation, it was hard to tell where field ended and factory began.[42] By the late 1870s, however, proponents of the centralization of sugar production in the Caribbean and elsewhere wrote of the need for a strict "division of labor."[43] This phrase referred not to specialization of tasks within the factory itself nor to the routinization of previously skilled work. Rather, it meant separating the agricultural zone where sugar cane was grown from the mill where it was ground and processed for sale.[44] This separation was, as most owners and boosters of central factories articulated it, chiefly legal, financial, and economic. It was, they claimed, the only lesson to be drawn from the success of beet-sugar producers in Europe, whose factories owned no agricultural land, only purchasing their beet supplies through contracts with independent farmers. Such strict distinction between the interior and exterior of a central, both in reality and in rhetoric, proved to be important as chemists sought to conceive of the space within the factory as one that was like a laboratory. This was true even as controlling a factory meant a vast web of disciplinary and measurement practices that extended beyond the bench, out of the laboratory, past the gates of the central, and to distant outposts in the cane fields.

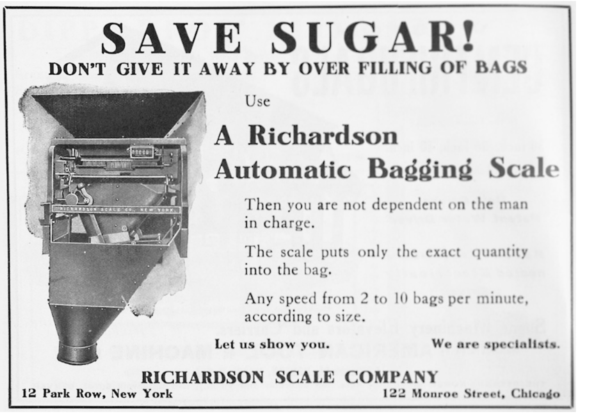
The Vacuum Pan and the Limits of Control

Within the industrial sugar factory, chemists played crucial roles and oversaw laborious regimes of sampling, testing, and analysis, all of which fell under the term *chemical control*.[45] As with much metrological work elsewhere across the history of the sciences, the work chemists performed in enforcing the uniformity of sugar has been left unwritten; in acting as their own intradisciplinary historians, chemists themselves have sometimes contributed to this neglect.[46] And by divorcing industrial sugar manufacture from skilled labor, historians have misunderstood the term: *chemical control* meant the control of human labor.

Watching Soledad from Boston, Atkins demanded both weekly laboratory reports and monthly statements from his chemists.[47] That allowed him to tell the chemists exactly how much sucrose he wanted in his sugars. After Soledad began grinding its 1890 crop, Atkins was pleased to hear of how much it was extracting but ordered his chemist to go no further: "95½ avg. test is as high as I wish[;] it is useless to make it higher."[48] In observing, measuring, and calculating the chemistry of sugar processing, chemists' employers hoped to exert coercive control over their once autonomous labor force. Conversely, dictating the behaviors of their workforce was to be the means by which factory owners could control parts of the sugar-making system that defied calculation and analysis.

The writings on "control of the factory" by Noël Deerr, the sugar industry's most widely traveled and respected sugar chemist, can teach us much about how the program of chemical control was envisioned by proponents.[49] Such books invariably began with exhortations: "A modern factory must be conducted from the mill to the distillery as a huge chemical experiment."[50] But his books also showed where sugar chemists should compromise and where they must not. "No hard and fast rules can be laid down for the determination of yield and losses," Deerr admitted; "a great deal depends on the skill and ingenuity of the chemist." Even as he depicted an idealized version of laboratory and factory, Deerr also explicitly acknowledged and implicitly revealed the way chemical practitioners had to negotiate with the other human beings who populated the cane-sugar world and with the material limitations and environmental realities of sugar production. It was the uncertainty of chemical administration that made a trained chemist the only one who could achieve it.[51]

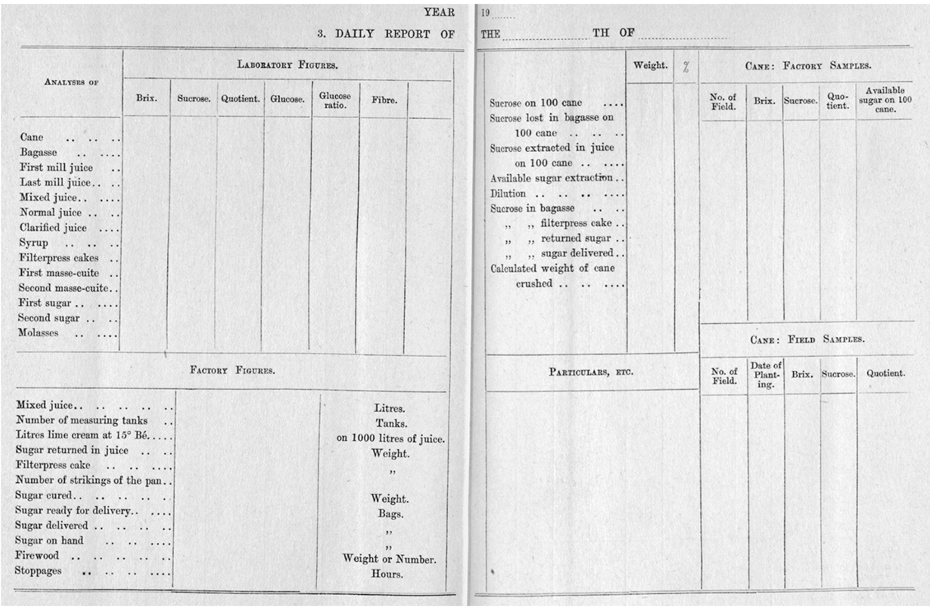
Figure 3. The makers of automatic measuring devices for sugar factories told superintendents that "you are not dependent on the man in charge." From American Sugar Industry and Beet Sugar Gazette, vol. XIV, no. 1 (January 1912), page 6.



The most important number for accounting for sugar within the factory was the amount that entered it trapped in cane. That number depended on accurate readings of the weight and on how closely to the factory such weight could be taken. In weighing canes, Deerr extolled confirmation of the "exactitude" of the scales themselves and calibration of "the (in general) native [*sic*] operator." Ideally, "automatic" balances that were "self-registering" put any potential manipulation "beyond the control of the attendant, whose functions are [now] merely mechanical."[52] Atkins, for instance, was disturbed by weight that sugar cargoes gained between Cuba and Boston, "against the usual gain of ¾ of one per cent" that might be attributed to the absorption of moisture. He pressed Skaife to "inquire carefully into the weighing and see if our weigher is giving us full weight."[53] Skaife duly reported that he found nothing amiss—that he was satisfied with the regime of numerical control he had established.[54] The arrival of the cane by rail facilitated such efforts at control, since railroad scales could weigh entire cars against their tare set at the beginning of the season.[55] At the large Puerto Rican Central Guanica, the general manager was an ex-railroad employee who made sure to check the cane, juice, and sugar scales with standard weights at least twice a week (fig. 3).[56]

Deerr emphasized that human error on the part of the sugar factory's own workers caused most losses of sugar, even if the culprit was "very hard to determine directly."[57] At the same time as chemists expressed mistrust of the workforce, however, treatises on chemical control also revealed the degree to which the actual practical work of a factory chemist depended on the workers themselves. A chemist who worked at a Louisiana factory in the late 1880s later recalled the enormous task he had faced. He wanted to test the mill juice, the clarified juice, the evaporator syrup, the massecuites after boiling, and the sugar and molasses themselves. "Each of these several products had to be accurately measured or weighed and, with sixty or seventy analyses a day, I had to spend an average of eighteen hours a day in the laboratory."[58]

Consider, too, the way Deerr suggested determining the sugar content of



YEAR 19........

3. DAILY REPORT OF THE .... TH OF ....

Analyses of	Laboratory Figures. Brix.	Sucrose.	Quotient.	Glucose.	Glucose ratio.	Fibre.	
Cane							
Bagasse							
First mill juice ..							
Last mill juice.. ..							
Mixed juice..							
Normal juice							
Clarified juice							
Syrup							
Filterpress cakes ..							
First masse-cuite ..							
Second masse-cuite..							
First sugar							
Second sugar							
Molasses							

Factory Figures.		
Mixed juice..		Litres.
Number of measuring tanks ..		Tanks.
Litres lime cream at 15° Bé.....		on 1000 litres of juice.
Sugar returned in juice		Weight.
Filterpress cake		,,
Number of strikings of the pan..		
Sugar cured..		Weight.
Sugar ready for delivery..		Bags.
Sugar delivered		,,
Sugar on hand		,,
Firewood		Weight or Number.
Stoppages		Hours.

	Weight.	%
Sucrose on 100 cane		
Sucrose lost in bagasse on 100 cane		
Sucrose extracted in juice on 100 cane		
Available sugar extraction..		
Dilution		
Sucrose in bagasse		
,, ,, filterpress cake ..		
,, ,, returned sugar ..		
,, ,, sugar delivered..		
Calculated weight of cane crushed		

Particulars, etc.

Cane: Factory Samples. No. of Field.	Brix.	Sucrose.	Quotient.	Available sugar on 100 cane.

Cane: Field Samples. No. of Field.	Date of Planting.	Brix.	Sucrose.	Quotient.

Figure 4. A model for a sugar-factory chemist's daily report, showing the number and variety of tests required, which the author noted could be completed only with "native assistance." H. C. Prinsen Geerligs, Methods of Chemical Control in Cane Sugar Factories (Altrincham: Norman Rodger, 1905), pages 78–79.

canes. In a factory grinding sixteen carloads of cane per hour, he retrieved one cane shoot from each car, then cut the top sixteenth of the first cane, the second sixteenth of the second, and so on, down to the sixteenth part of the sixteenth cane. These sixteenths were knifed into halves, then into quarters, and eventually into eighths, producing a final sample of between two hundred and three hundred grams. "Proceeding systematically on these lines," he wrote, "as many as 100 canes can easily be analysed in a day of eight hours." But for one chemist alone, so much cutting would be very hard work—and this was only the beginning of his supposed "control."[59]

So it was no surprise that Deerr admitted that in many cases "the necessary control work of a sugar factory is performed by unskilled assistance."[60] He acknowledged that "by simple analyses, such as can be performed by any member of the estates' [*sic*] staff, combined with attention to correct measurements and sampling, valuable and reliable data can be obtained."[61] Other chemists, in their own handbooks, textbooks, treatises, and manuals, spoke of how "samples of materials at essential process points were collected continuously," without mentioning by whom (fig. 4).[62] The chief chemist of the Cuban-American Sugar Company asked in his *Hand-Book for Sugar Manufacturers* whether one chemist could perform all that was necessary for factory control. "If the chemist is located in a house provided with crude measuring apparatus, where he must superintend his own sampling and keep a watchful eye on his employés, he will require several assistants."[63] The sugar chemist's control over the factory workforce depended on collaboration with that workforce itself.

And more often than not it was chemists who were in charge of that workforce. "The manager, engineer, or chemist must not only know what has to be done," wrote Thomas Heriot, a West Indian factory chemist who organized a school for cane sugar manufacture in Glasgow, "but must be able to direct those who do it, and to see that their instructions are being carried out."[64] At Soledad, for instance, where the chemist earned $1,500 a year in the 1880s plus expenses, the person who occupied that position was also the superintendent of the human operations of the sugar house, while the mills themselves and the machinery were overseen by the chief engineer.[65]

When Atkins's general manager departed in 1894, Skaife, his chemist, pushed for complete control. He suggested that "all *technical* questions concerning the mill house and boiling house ought to be referred in the first instance to me." He argued that the chemist's domain was coterminous with the factory itself, both for reasons of efficiency and by right. "Let it be understood that the cane is delivered to me [outside the factory] and there my responsibility begins."[66] A few weeks later he tried again: "There would be little or no difference as regards the routine work but I could put at your disposal a good deal of knowledge and experience which is now rather wanted, for I have been a long time in the business and can manage men."[67]

The most important people whom chemists like Skaife commanded were those directly responsible for crystallizing the sugar, known as sugar boilers or (vacuum) "pan men." An index of their importance is that Atkins made time among his many other responsibilities to hire these people himself. He spent a great deal of time every off-season evaluating the performance of his current pan operators and negotiating their salaries or granting them bonuses, even as he evaluated job applicants for the position, scheduled face-to-face meetings with potential new hires in person, and arranged training to complement the skills they already possessed.[68]

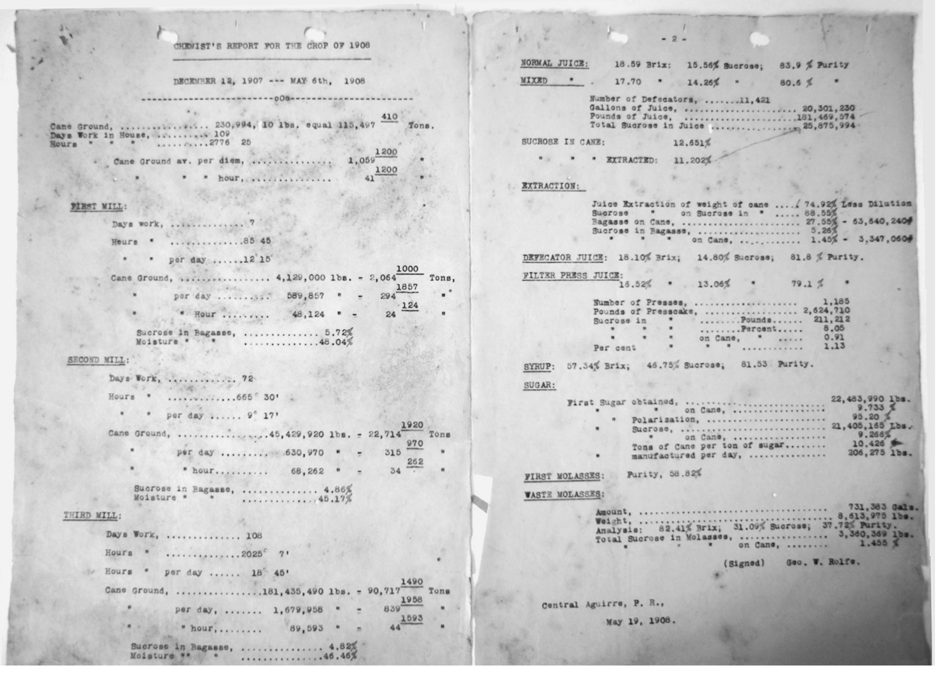
The pan operators were crucial because, despite decades of ownership's efforts to automate skill in sugar production and transform it from a discrete to a continuous process more suitable for control, there was one crucial point of the process where they were frustratingly unable to calculate skill away.[69] That was the "strike" from the vacuum pan and the abilities required to accomplish it. If the centrifugal was taken to represent the new qualities of sugar, the vacuum pan has been most closely tied to the notion that craft knowledge was no longer required to make it. In the central, the sugar master's expertise at discriminating among the qualities of the loaf was allegedly rendered irrelevant by the uniformity of centrifugal sugar.[70] Moreno Fraginals concluded the first volume of *The Sugarmill* with an elegy on the chemical dissolution of the sugar master's authority: "His loss of supremacy came when vacuum pans were introduced and his judgment was replaced by physical measuring apparatuses."[71] Yet sugar chemists themselves were more circumspect, consistently reluctant to make promises of control over a process that was mostly opaque and from which visual access did not yield much insight. In their reluctance the limits of chemical control are visible.

The amount of syrup that the pan operator allowed into the pan had to be of just the right volume so that when sugar crystallized out of the syrup it would make maximum use of the space in the pan. Here the economy of the sugar factory, and the maximization of the capital invested in the expensively fragile vacuum pan, depended on the "brain under the workman's cap."[72] The process of crystallization required more syrup to be gradually allowed into the pan in order to regulate the growth and size of the crystals, as well as their sucrose content. Yet the quality of the sugar crystals could not be determined during the crystallization process. Only once the pan was struck into the centrifuges could the resulting massecuite be tested.

Whether the juice was of poor quality or from healthy canes produced under the central's own supervision, the task was never mechanical or reducible to calculable quantities. Chemical expertise could produce no formula that turned the temperature and flux of syrup into all the factors that constituted what was called the sugar's "character"—what might make sugar "very wet & a little sour" or cause one of Atkins's lots to "lose in color and turn red" while leaving the next "as bright as the day they were made, free from grain and hav[ing] a hard gritty feeling like dry sand."[73] The superintendent of Puerto Rico's massive Central Aguirre, who during the offseason taught chemistry at the Massachusetts Institute of Technology, emphasized that "long experience and familiarity with the workings of his pan are essential qualifications of a first-class sugar boiler." The result was that boilers "command high pay and have much responsibility" (fig. 5).[74]

But the boilers' incalculable skill could be used against them. To Deerr, "the determination of the crystallised sugar . . . affords a valuable check on the pan-boiler," especially that boiler's conscientious deployment of skill.[75] Through the factory's chemist the owner might specifically order the pan operator to "keep his temperature down and boil a medium grade" for a particular cargo, if it might be sold in transit and thus not suffer financial loss from degradation.[76] Just as with automatic weighing machines, measurement of the sugar content of massecuites afforded another opportunity in the chemist's eyes for a check on theft.

In the middle of the 1894 harvest Skaife had to report to Atkins that he had fired a sugar boiler. He had thrown insults and a punch at Skaife while intoxicated, Skaife explained, "because I asked him very quietly to put down the time of starting molasses strikes which he was neglecting."[77] What was at stake in these fisticuffs was whether knowledge about sugar boiling was the property of the artisan or the chemist. In subsequent weeks Skaife had to work unsustainably long hours to compensate for the absent employee. But he did not directly operate the pans, leaving that task to the boiler who remained.[78] The position of the pan operator was fundamentally an anxious and precarious one, but so was that of the chemist who oversaw him.



CHEMIST'S REPORT FOR THE CROP OF 1908

DECEMBER 12, 1907 --- MAY 6th, 1908

------------------------o0o------------------------

Cane Ground, ... 230,994, 10 lbs. equal 115,497 $^{\underline{410}}$ Tons.
Days Work in House, ... 109
Hours " " " 2776 25

Cane Ground av. per diem, ... 1,059 $^{\underline{1200}}$ "
" " " hour, ... 41 $^{\underline{1200}}$ "

FIRST MILL:

Days work, ... 7
Hours " 85 45
" " per day 12 15
Cane Ground, ... 4,129,000 lbs. - 2,064 $^{\underline{1000}}$ Tons,
" per day .... 589,857 " - 294 $^{\underline{1857}}$ "
" " Hour .... 48,124 " - 24 $^{\underline{124}}$ "
Sucrose in Bagasse, ... 5.72%
Moisture " " 48.04%

SECOND MILL:

Days Work, ... 72
Hours " ....665° 30'
" " per day ...... 9° 17'
Cane Ground, ...45,429,920 lbs. - 22,714 $^{\underline{1920}}$ Tons
" per day .... 630,970 " - 315 $^{\underline{970}}$ "
" " hour.......... 68,262 " - 34 $^{\underline{262}}$ "
Sucrose in Bagasse, ... 4.86%
Moisture " " 45.17%

THIRD MILL:

Days Work, ... 108
Hours " ....2025° 7'
Hours " per day ...... 18° 45'
Cane Ground, ...181,435,490 lbs. - 90,717 $^{\underline{1490}}$ Tons
" per day, ... 1,679,958 " - 839 $^{\underline{1958}}$ "
" " hour,........ 89,593 " - 44 $^{\underline{1593}}$ "
Sucrose in Bagasse, ... 4.82%
Moisture "" " 46.46%

- 2 -

NORMAL JUICE: 18.59 Brix: 15.56% Sucrose; 83.9 % Purity
MIXED " . 17.70 " 14.26% " 80.6 % "

Number of Defecators, ...11,421
Gallons of Juice, ... 20,301,230
Pounds of Juice, ...181,469,574
Total Sucrose in Juice 25,875,994

SUCROSE IN CANE: 12.651%
" " " EXTRACTED: 11.202%

EXTRACTION:

Juice Extraction of weight of cane ..... 74.92% Less Dilution
Sucrose " on Sucrose in " 88.55%
Bagasse on Cane, ... 27.55% - 63,640,240#
Sucrose in Bagasse, ... 5.26%
" " " on Cane, ... 1.45% - 3,347,060#

DEFECATOR JUICE: 18.10% Brix; 14.80% Sucrose; 81.8 % Purity.

FILTER PRESS JUICE:
16.52% " 13.06% " 79.1 % "

Number of Presses, ... 1,185
Pounds of Presscake, ... 2,624,710
Sucrose in " ....Pounds...... 211,212
" " " ....Percent..... 8.05
" " " on Cane, " 0.91
Per cent " " " 1.13

SYRUP: 57.34% Brix; 46.75% Sucrose; 81.53 Purity.

SUGAR:

First Sugar obtained, ... 22,483,990 lbs.
" " on Cane, ... 9.733 %
" Polarization, ... 95.20 %
" Sucrose, ... 21,405,165 Lbs.
" on Cane, ... 9.266%
Tons of Cane per ton of sugar......... 10.426
" manufactured per day, ... 206,275 lbs.

FIRST MOLASSES: Purity, 58.82%

WASTE MOLASSES:

Amount, ... 731,383 Gals.
Weight, ... 8,613,975 lbs.
Analysis: 82.41% Brix; 31.09% Sucrose; 37.72% Purity.
Total Sucrose in Molasses, ... 3,360,369 lbs.
" " " on Cane, ... 1.455 %

(Signed) Geo. W. Rolfe.

Central Aguirre, P. R.,
May 19, 1908.

Figure 5. The chemical report for the crop of 1908 at Central Aguirre in Puerto Rico, signed by its superintendent, the MIT chemist George Rolfe. Archivo General de Puerto Rico, Fondo Corporación Azucarera de Puerto Rico, Serie: Central Mercedita.

Sucrose, Metrology, and Capitalism

For a crop that depended so significantly on coordination between agriculture and processing, scattered ownership of the cane fields made it more difficult to coordinate planting and harvest schedules. Thus centrals attempted to exert control through contracts that strictly defined how and when the cane was to be grown, harvested, and delivered.[79] Yet it was hard to specify, and harder to measure, the quality of the cane delivered or its suitability for grinding.[80] In the early twentieth century, the labor of chemists became the focus of conflict between *colonos* and centrals.

Contracts between the two had most often been denominated in pounds of sugar per hundredweight of cane delivered.[81] Ordinarily, between five and seven pounds of sugar per hundred of cane were returned to growers, which they could sell themselves or ask the central to sell on their behalf (for a fee).[82] Such weight-based contracts, according to centrals and their chemists, yielded cane that was liable to be poorer quality and filled with "cane trash." If the *colonos* were paid based on the measured purity of the cane they transferred to the central, they argued, then *colonos* would have an "incentive to raise a high quality of cane and to deliver it in the best possible conditions."[83] José Solá has found that at least one Puerto Rican central paid *colonos* based on the density of their cane juice as early as 1906. Notably, this central was owned by a syndicate from Belgium, a country with a long history of beet-sugar production.[84] After 1921, as sugar prices remained low in the wake of the post–world war crash and as chemical forms of knowledge became entrenched throughout the sugar factory, contracts came to be denominated in terms of sucrose content as measured by the central's chemists. By 1928, the insular government of Puerto Rico registered 605 weight contracts and 178 sucrose contracts.[85]

But this system placed obvious advantages in the hands of the central, as the *colono* delivering to a mill "could not *know* whether he was fairly treated or not."[86] The juice of the cane could only be analyzed after it was crushed, and therefore all the power to decide the value of cane rested in the hands of the mill and its laboratory. For the *colono*, as one complained to a pair of US researchers, the system was a "funnel in which his end is the little end."[87] The *colonos* sought redress through the state. In the mid-1930s they succeeded in passing legislation to establish a force of chemists under the auspices of the government itself and to mandate the percentage of sucrose a *colono* received. The insular division of inspection, established in 1934, was staffed by five chemists authorized to obtain and analyze samples of cane juice from a *colono* and "contrast with the analyses made at the laboratory" of the factory. They were to serve as a referee of each "controversy" between *colono* and factory, to dictate "the rules and system for taking samples and analyzing the cane juices," and to register all chemists and chemical engineers.[88]

By then each American company dictated its own particular terms of payment to its *colonos*. These varied considerably, from Central Aguirre, which paid 65 percent of the expected recovery of sugar at New York prices minus freight, to Central Cambalache, which abandoned the analysis of each *colono*'s cane but returned to paying 7 percent by weight by the mid-1930s. The managers of Cambalache, which drew on many smaller growers, decided against the expense of chemical labor required to draw samples from each shipment.[89] All the centrals complained that competitors "sweetened" their numbers to lure growers, while *colonos* complained that mills found an excessive number of demerits to reduce their payment. Individually, each central defended its own idiosyncratic formula by pointing to an increasing body of chemists' evidence. But together, the effect of multiple contradictory formulas paradoxically was to reinforce a widespread sentiment among *colonos* that those same formulas were never purely "non-economic and technical in character."[90] How else but malfeasance to explain the differences among them, on the part of centrals that claimed access to reserves of objective chemical knowledge? Legislation to standardize the formula for the remuneration of cane growers all over the island was intended to clarify that the clash of interests between mills and *colonos* was an economic one, fought over the fraction of the price of sugar that each should receive. But this conflict had, of course, been present in the formula all along.

This essay has explored the nature of labor under the scientific regimes that attempted to govern the new industrial sugar factories of the American sugar empire in the Caribbean. The revolt against contracts denominated in chemical terms highlights yet another way in which the supposedly mechanical power of the central to transform cane into sucrose actually depended on various kinds of contested skill. Chemical control sought to design procedures and machines to eliminate the need for skilled labor in sugar making, yet still depended on artisanal knowledge at crucial points.

The more persuasively chemists described the factory as a laboratory or as a machine, and the more they established the equation of pure sugar and sucrose, the more they rendered their own hard work invisible alongside that of the artisans. The social machinery of commodification seems to function on its own precisely because of such elaborate human systems for assaying commodities' properties.[91] Paying attention to the construction of commodities' apparently universal metrology helps to dismantle the mechanical image of commodification itself. Meanwhile, histories of capitalism that emphasize the systematic transformation of nature into goods have neglected the crucial labor of intermediaries who made such empires of commodities possible. In doing so, these histories may actually help make the structures and institutions of commodification appear stable and automatic. But there is never a point at which harvests or herds sublimate into interchangeable commodities, because commodification is not a process that can be mechanized or automated. Rather, commodification is a continuous and continual effort, in which human beings, granted privileged positions as arbiters of value, must constantly reaffirm that idiosyncratic natural specimens are fundamentally the same.

David Roth Singerman is a visiting scholar in American Studies and at the Centro de las Americas at the University of Virginia. He received his PhD in 2014 from the Program in Science, Technology, and Society at the Massachusetts Institute of Technology (MIT). His dissertation, "Inventing Purity in the Atlantic Sugar World, 1860–1930," was awarded prizes for best dissertation in 2015 by the Business History Conference in the United States and the Association of Business Historians in the United Kingdom. "Inventing Purity" is the basis of his current book project, titled "Purity and Power in the American Sugar Empire."

Notes

1. Ortiz, *Cuban Counterpoint*, 9, 49.
2. Ibid., 24–25.
3. Ibid., 9.
4. Higman, "Sugar Revolution."
5. Atkins, *Sixty Years in Cuba*, 1.
6. Ibid., 109.
7. Montgomery, *Fall of the House of Labor*; Kumar, *Indigo Plantations and Science*; for sugar, see Moreno Fraginals, "Plantations in the Caribbean"; Dye, "Avoiding Holdup"; Iglesias García, *Del ingenio al central*; Heitmann, *Louisiana Sugar Industry*; Ramos Mattei, *La hacienda azucarera*; García Muñiz, *Sugar and Power*; Pretel and Fernández-de-Pinedo, "Circuits of Knowledge."

8. Moreno Fraginals, "Plantations in the Caribbean," 3, 7–10.
9. Atkins, *Sixty Years in Cuba*, 109–10.
10. Moreno Fraginals, "Plantations in the Caribbean," 7.
11. Schaffer, "Late Victorian Metrology"; Schaffer, "Accurate Measurement."
12. Cronon, *Nature's Metropolis*; Johnson, *River of Dark Dreams*; Beckert, *Empire of Cotton*. For a critique of the perspective of such works, see Rood, "Beckert Is Liverpool"; Hudson, "Racist Dawn of Capitalism." A valuable corrective to this metrological tendency is Hahn, *Making Tobacco Bright*.
13. Schaffer, "Golden Means"; Linebaugh, *London Hanged*; Lucier, *Scientists and Swindlers*; Noble, *Forces of Production*; Roberts, Schaffer, and Dear, *Mindful Hand*.
14. Merleaux, *Sugar and Civilization*.
15. Tomich, "Commodity Frontiers," argues that the scale and environmental conditions of the Cuban "sugar frontier" allowed its mills to reshape the structure of the world market.
16. Mintz, "Plantation as Socio-Cultural Type."
17. Atkins to J. George Lumilius, November 11, 1989, II.8.361, Edwin F. Atkins Papers, Massachusetts Historical Society (hereafter cited as MHS), Boston, Massachusetts.
18. García Muñiz, "Louisiana's 'Sugar Tramps.'"
19. As David F. Noble wrote of petroleum industries in the 1940s: "Up to now the workers had somehow successfully run refineries without the aid of reason, but management was no longer willing to rely upon such routine miracles." Noble, *Forces of Production*, 63.
20. García Muñiz, "Louisiana's 'Sugar Tramps,'" 5.
21. Fernández Prieto, "Saberes híbridos"; McCook, *States of Nature*; Rood, "Plantation Technocrats."
22. Dunn, *Sugar and Slaves*; Galloway, *Sugar Cane Industry*; Pares, *West-India Fortune*; Otremba, "Enlightened Institutions"; Otremba, "Inventing Ingenios."
23. Dunn, *Sugar and Slaves*, 195.
24. Smith, "Creating an Industrial Plant."
25. Moreno Fraginals, *Sugarmill*, 116.
26. Martin, *Essay on Plantership*, 23.
27. Moreno Fraginals, *Sugarmill*, 116.
28. Portuondo, "Plantation Factories," 251.
29. Heitmann, *Louisiana Sugar Industry*, 25–32.
30. Reproduced in Moreno Fraginals, *Sugarmill*, 145–48. Earlier historians who extolled the progressive industrialization of sugar production suggested that "wastefulness and slovenliness" were the predominant characteristics before the central factory and its machines. See, e.g., Beachey, *British West Indies*, 61. In fact, as Rosenthal shows in "From Memory to Mastery," it was precisely because labor on a slave plantation was in theory subject to round-the-clock oversight that planters could both enforce the collection of information and calculate its utility.
31. Ligon, *Island of Barbados*, 85, 91.
32. Roberts, "Death of the Sensuous Chemist."
33. Marggraf, "Expériences chymiques faites dans le dessein," 79, 80; author's translation, emphasis added.
34. Klein, *Materials in Eighteenth-Century Science*, 200.
35. Curry-Machado, *Cuban Sugar Industry*; Cabrera Salcedo, *De los bueyes al vapor*. For the exhaustive standard history of the varieties of technologies of sugar production, see Deerr, *History of Sugar*, vol. 2.

36. Galloway, *Sugar Cane Industry*, 137. See also Beachey, *British West Indies*, 68; Curry-Machado, *Cuban Sugar Industry*, 27.
37. See esp. Fernández Prieto, "Saberes híbridos"; Rood, "Plantation Technocrats"; Curry-Machado, *Cuban Sugar Industry*.
38. Galloway, Sugar Cane Industry, 134. For financial networks of North American control over sugar factories in the Caribbean post-1898, see Ayala, *American Sugar Kingdom*, and Ramos Mattei, "Las inversiones norteamericanas." For contemporary surveys of the ownership of Puerto Rican sugar factories at the turn of the century, see Pagan, *Biografia de las riquezas*.
39. Guerra y Sánchez, *Sugar and Society*.
40. Zanetti Lecuona and García Alvarez, *Sugar and Railroads*.
41. Peñaranda, *Cartas puertorriqueñas*, 87–89. Author's translation. For Central San Vicente, see Martínez-Vergne, *Capitalism in Colonial Puerto Rico*, and Ramos Mattei, *La sociedad del azúcar*.
42. Mintz, *Sweetness and Power*, 47. For narratives of industrialization, see Schaffer and Roberts, preface to *The Mindful Hand*, xiii–xxvii.
43. For non-Caribbean advocacy of the central system, see, e.g., the Louisiana planter John Dymond's "Louisiana Sugar Industry"; cf. Heitmann, *Louisiana Sugar Industry*, 66. For Mauritius, see de Boucherville, "L'avenir d'une Colonie sucrière," 464.
44. García Muñiz, "Louisiana's 'Sugar Tramps.'" For the similar division in beet production, see Perkins, "Political Economy of the Sugar Beet."
45. Heriot, *Science in Sugar Production*, 14.
46. Horne, "Contributions of the Chemist," 278–79.
47. Skaife to Atkins, April 30, 1894; Skaife to Atkins, May 24, 1894; Atkins to Skaife, May 7, 1894, II.12.59, MHS.
48. The market in the United States was structured by the government's tariff, which set 96 percent as the boundary between raw and refined sugars. Atkins to Terry, December 31, 1889, II.8.471, MHS. For numbers as a technology of accountability and distance, see Deringer, "Finding the Money," and Porter, *Trust in Numbers*.
49. Deerr, *Sugar and the Sugar Cane*; Zanetti Lecuona, *Delgado*, and García Muñiz, "Noël Deerr."
50. Deerr, *Sugar and the Sugar Cane*, 281.
51. Ibid., 296.
52. Ibid., 282–83.
53. Atkins to Skaife, May 4, 1894, II.12.50, MHS.
54. Skaife to Atkins, May 14, 1894, MHS.
55. Heriot, *Science in Sugar Production*, 14.
56. Edson, *From Scarcity to Surplus*, 95.
57. Deerr, *Sugar and the Sugar Cane*, 295–96.
58. Edson, *From Scarcity to Surplus*, 52.
59. Ibid., 329.
60. Deerr, *Sugar and the Sugar Cane*, 327.
61. Ibid., 281.
62. Edson, *From Scarcity to Surplus*, 95.
63. Spencer, *Hand-Book for Sugar Manufacturers*, 16.
64. Heriot, "Technical Training," 178.
65. Atkins to Lumilius, November 11, 1889.
66. Skaife to Atkins, June 8, 1894, MHS; emphasis in the original.

67. Skaife to Atkins, June 24, 1894, MHS.
68. Atkins to Herbert Konig, October 26, 1887, II.7.329; Atkins to August Heyne, May 11, 1888, II.7.415, and May 18, 1888, II.7.430; Atkins to Arthur Siebert, May 23, 1888, II.7.435, MHS.
69. Pretel and Fernández-de-Pinedo, "Circuits of Knowledge," 271. For continuous processes and control of work, see Montgomery, *Fall of the House of Labor*, 55–56.
70. Moreno Fraginals, *Sugarmill*, 145–48.
71. Ibid., 153.
72. Montgomery, *Fall of the House of Labor*, 9.
73. Atkins to Jose Montalvo, May 27, 1885, II.6.113–15; Atkins to Charles E. Fowler, June 10, 1885, II.6.147–54, MHS.
74. Rolfe, *Polariscope in the Chemical Laboratory*, 131. For Aguirre, see García Muñiz, *Sugar and Power*. For Rolfe, see MIT Annual Report of the President and Treasurer, 29.
75. Deerr, *Sugar and the Sugar Cane*, 347.
76. Atkins to Terry, December 23, 1887, II.7.371–72, MHS.
77. Skaife to Atkins, April 30, 1894.
78. Skaife to Atkins, May 7, 1894, MHS.
79. Ayala, *American Sugar Kingdom*; Dye, "Avoiding Holdup"; Dye, *Cuban Sugar*.
80. Spencer, *General Instructions and Methods*, 16.
81. Brookings Institution, *Sugar Problem*.
82. Scott, *Degrees of Freedom*, 117; Ayala, *American Sugar Kingdom*, 133.
83. Brookings Institution, *Sugar Problem*, 17–19.
84. Solá, "Funnel system," Appendix A.
85. Ibid., 19.
86. Gayer, Homan, and James, *Sugar Economy*, 137; emphasis in the original.
87. Solá, "Funnel system," 7; for the political alliances of *colonos* see Solá, "Colonialism."
88. Laws of Puerto Rico (1934), no. 71, secs. 1, 4. A subsequent law authorized *colonos* not just to observe but also to intervene in "the taring of cars, weighing of sugar, examination of scales, weighing of cane and juice, taking of samples and analyses of cane." See *Laws of Puerto Rico* (1937), no. 112, sec. 14.
89. For Cambalache, see García Muñiz, *Sugar and Power*, 81.
90. Gayer, Homan, and James, *Sugar Economy*, 275–77.
91. For superb studies of the process of assigning value, see Hecht, *Being Nuclear*, and Lépinay, *Codes of Finance*. See also Alder, "Making Things the Same"; Callon and Rabeharisoa, "Economy of Qualities."

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