Introduction: "A More Intimate Acquaintance"

Lissa L. Roberts and Simon Werrett

Power, transformation, promise, subjugation: terms that might easily be invoked to describe the decades between 1760 and 1840. Together they point toward the multi-faceted developments through which Europe took on its modern character and dominant position in the world – what this volume refers to as 'compound histories'. Simultaneously linked to the Baconian dictum that 'knowledge is power' and the brute facts of power-driven conquest and exploitation, this period is characterized by the historical tensions through which the promise of progress and subjugation of regions and resources around the world fed off and gave rise to social, political, economic, cultural, scientific, technological and environmental transformations. It was a time marked by the interactive appearance of new, janus-faced forms of political organization, scientific and technological capabilities, social and economic configurations: the growth of democracy coupled with empire; increasing abilities to harness the material world and its forces for productive ends coupled with destructive wars and environmental degradation; opportunities for great wealth creation coupled with new strains of poverty and deprivation.

It is this complex weave and the question of what binds its threads together that continue to make the 'age of revolution' so intriguing to historians.[1] While there is certainly no single answer to this question, which requires insights drawn from multiple subdisciplines of history, the contention undergirding this volume is that one key element has been insufficiently explored and integrated into the larger picture of historical development. Rather than baldly state what that is, let us turn to a voice from the period itself. In 1805 John Playfair, Edinburgh professor of natural philosophy, wrote:

> Nature, while she keeps the astronomer and the mechanician at a great distance, seems to admit [the chemist] to a more intimate acquaintance with her secrets. The vast powers which he has acquired over matter, the astonishing transformations which he effects, his success in analysing almost all bodies, and in reproducing so many, seems to promise that he

1 E.J. Hobsbawm, *The Age of Revolution: Europe 1789-1848* (London: Weidenfeld and Nicholson, 1962).

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> shall one day discover the essence of a substance which he has so thoroughly subdued.[2]

Playfair viewed chemistry as the foremost scientific agent of the terms we have identified as defining this period of history. The growing powers chemists exercised over the material world, he declared, were leading to its subjugation, yielding "astonishing transformations" and the promise of understanding and absolute control. Though Playfair limited his remarks to the relations between humans and the material world, he and countless others recognized and engaged with chemistry in ways that brought the material and social realms together. Through their manipulative interactions with an increasing range of materials, chemists and chemistry left their mark virtually everywhere: increasing agricultural yields, expanding the range and scale of industrial production, extending the reach and precision of governance programs and practices, spearheading social improvement and public health. But so too did they contribute to environmental degradation through the unbridled exploitation of resources and aggravated industrial pollution, as well as to unsafe labor conditions and misery, the ferocity of warfare and the rapacious practices of empire.

The purpose of this volume is to raise broader attention to the position that chemistry was once recognized to hold as an active component of the great economic, social, and political developments of the period 1760-1840. It aims to do two things. First, by exploring the historically intertwined realms of production, governance and materials, it places chemistry at the center of processes most closely identified with the construction of the modern world. This includes chemistry's role in the interactive intensification of material and knowledge production; the growth, direction and management of consumption; environmental changes, regulation of materials, markets, landscapes and societies; and practices embodied in political economy. Second, the volume moves away from a narrative structured by a revolutionary break at the end of the eighteenth century and the primacy of innovation-driven change. Instead it aims to highlight the continuities and accumulation of less momentous changes that framed historical development over time and across the various spheres (the academic world, manufactures, public health and medicine, governmental administration, civil society and agriculture) in which chemists and chemistry operated.

Standard historical surveys tend to ignore eighteenth and early nineteenth-century chemistry – at best mentioning Lavoisier and the Chemical Revolution – or to subordinate it to physics and the mathematical sciences. Mechanization and quantification are often privileged as prime movers of historical change,

2 John Playfair, "Biographical Account of Hutton," *Transactions of the Royal Society of Edinburgh* 5 (1805): 39-99, on 74.

joined (finally) by chemistry in a 'second industrial revolution' during the final decades of the nineteenth century.[3] Switching from generalities to the more detailed practices of governance and production in the period 1760 to 1840, however, reveals a different story. This volume recognizes chemistry as broadly integrated in daily life, as essential to industrial development and agricultural improvement, and as fundamental to the governance of both society and the environment.

Crucial to such discussions is the question of who was a chemist. Should this label be applied only to those attached to universities and scientific academies or to a broader range of actors who engaged in chemical practices? If the latter, apothecaries, mining officials, manufacturers, inventors and others should and have been investigated as part of the history of chemistry.[4] Historians have recently asserted the existence of 'chemical experts', who served as consultants or held administrative and management positions.[5] This has brought the history of chemistry into closer contact with the history of governance (the stimulation and management of both public and private enterprises), a central theme of this volume. Attention to the ambiguous legacy of chemist-consultants heightens our awareness of chemistry's equivocal hold on public authority. Sometimes identified as arbiters of product purity and with improving public health and welfare, chemists were also viewed with distrust for representing the interests of industry and furthering environmental degradation.[6]

The expanding franchise of chemical practitioners reflects another critical change in how the history of chemistry is and should be examined. Historians

3 Tore Frangsmyr, J.L. Heilbron, and Robin E. Rider, eds., *The Quantifying Spirit in the Eighteenth Century* (Berkeley: University of California Press, 1990); Pat Hudson, *The Industrial Revolution* (London: Bloomsbury, 2014); Daniel Roche, "Encyclopedias and the Diffusion of Knowledge," Mark Goldie, Robert Wokler, eds., *The Cambridge History of Eighteenth-Century Political Thought* (Cambridge: Cambridge University Press, 2006), 172-194 on 175; But see Archibald and Nan Clow, *The Chemical Revolution: A contribution to social technology* (London: Batchwork Press, 1952; John Graham Smith, *The Origins and Early Development of Heavy Chemical Industry in France* (Oxford: Clarendon Press, 1979).

4 Hjalmar Fors, *The Limits of Matter: Chemistry, mining and enlightenment* (Chicago: University of Chicago Press, 2015); David Philip Miller, *James Watt, Chemist: Understanding the origins of the steam age* (London: Pickering and Chatto, 2009); Jonathan Simon, *Chemistry, Pharmacy and Revolution in France, 1777-180*9 (Aldershot: Ashgate, 2013).

5 Ursula Klein, "Chemical Experts at the Royal Prussian Porcelain Manufactory," *Ambix* 60 (2013): 99-121.

6 See Thomas Le Roux' contribution to this volume; idem., "Chemistry and Industrial and Environmental Governance in France, 1770-1830," *History of Science* 54 (2016): 195-222; Christopher Hamlin, "The City as a Chemical System? The chemist as urban environmental professional in France and Britain, 1780-1880," *Journal of Urban History* 33 (2007): 702-728.

of chemistry are increasingly interested in the materials and material objects with which chemists interacted. Beyond a focus on the instruments, vessels and tools that furnished chemistry laboratories and workplaces, this includes chemistry's involvement in the histories of diverse materials through experimentation, consultation, regulation, and production improvement.[7] Materials and material objects were critical sites where chemistry met with governance and production between 1760 and 1840. Insofar as chemists could claim to manage the powers of airs, acids, minerals, metals, dyes and waters, so could they determine the habits, practices, and positions of those who engaged with these materials as manufacturers, regulators or consumers. When publicly recognized, chemists' knowledge and skill provided a platform for their claims of authority and expertise, which warranted their interventions in matters of governance. The essays in this volume work to identify such stances, positioning chemistry at the heart of the organization of social order.

To achieve these aims, this volume is divided into three sections.The first accentuates materials and material objects, along with the resources they provided chemical practitioners for building and exercising knowledge and expertise. The entangled nature of the social and material is also evident in the second section, on chemical governance, whereby chemists became involved in both the governmentally sanctioned and privately organized management of resources, people and environments. Finally, drawing on lessons from these two sections, the third revisits the classic theme of production, understood to include material and knowledge production, as well as their relation.

Materials and Material Objects

Given the centrality of materials and material objects to chemistry, attending to materiality as a key element of its history is bound to be a frutiful approach.[8] The traditional historiography of the "Chemical Revolution" certainly spoke of substances (phlogiston, calxes, oxygen, caloric) and instruments (the ice calorimeter, the balance), but too often in relation to the development of revolutionary ideas and concepts. Explorations that focus on their materiality have much to tell us about the details and consequences of chemical practice, which linked chemistry to broader historical developments.[9] Happily, historians are

7 Ursula Klein and Emma Spary, eds., *Materials and Expertise in Early Modern Europe: Between market and laboratory* (Chicago: University of Chicago Press, 2010).

8 Tom Ingold, "Materials Against Materiality," *Archeological Dialogues* 14 (2007): 1-16.

9 John G. McEvoy, *The Historiography of the Chemical Revolution: Patterns of interpretation in the history of science* (London: Routledge, 2010), 23-52; But see Lissa Roberts, "The Death

increasingly engaging with materials qua materials. Historians of early modern alchemy have used experiments and restagings to assess the particulars of alchemical recipes and procedures.[10] Scholars have long recognized the importance of instruments, and archaeology is now shedding light on historical chemical and alchemical instrumentation.[11] Catherine M. Jackson has analyzed how glassware altered nineteenth-century chemistry's laboratory practices and possibilities.[12] Historians have also expanded the repertoire of what counts as a chemically relevant material object by considering practitioners' interactions with a variety of commodities and substances.[13]

There is still, however, much to do. While there are now many histories of particular instruments and some distinct substances and spaces, we need to reflect more deeply on how to frame our inquiries. How should we approach the materiality of the substances and objects that populated and moved between the spaces in which historians are interested? Can we identify the broader practical and conceptual regimes of which these socio-material transformations were a part? How can we approach this subject without an *a priori* assumption that chemistry's development during this period depended on the introduction of innovative instruments and devices?[14]

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of the Sensuous Chemist: The 'new' chemistry and the transformation of sensuous technology," *Studies in History and Philosophy of Science Part A* 4 (1995): 503-529.

10 Pamela H. Smith at al, "The Making and Knowing Project" <http://www.makingandknowing.org/> accessed March 16, 2016; Lawrence M. Principe, "Apparatus and Reproducibility in Alchemy," Frederic L. Holmes and Trevor H. Levere, eds., *Instruments and Experimentation in the History of Chemistry* (Cambridge, MA: MIT Press, 2000), 55-74.

11 Trevor H. Levere, "The Role of Instruments in the Dissemination of the Chemical Revolution," *Endoxa* 19 (2005): 227-242; Frederic L. Holmes, *Eighteenth-century Chemistry as an Investigative Enterprise* (Berkeley, CA: Office for History of Science and Technology, University of California at Berkeley, 1989); Jan Golinski, "Precision Instruments and the Demonstrative Order of Proof in Lavoisier's Chemistry," *Osiris* 9 (1994): 30-47; Lissa Roberts, "A Word and the World: The significance of naming the calorimeter," *Isis* 82 (1991): 199-222; Marcos Martinón-Torres, "Inside Solomon's House: An archaeological study of the old Ashmolean chymical laboratory in Oxford," *Ambix* 59 (2012): 22-48; Simon Werrett, "Matter and Facts: Material culture in the history of science," Robert Chapman and Alison Wylie, eds., *Material Evidence: Learning from archaeological practice* (New York: Routledge, 2014), 339-352.

12 Catherine M. Jackson, "The "Wonderful Properties of Glass: Liebig's Kaliapparat and the Practice of Chemistry in Glass," *Isis* 106 (2015): 43-69.

13 Klein and Spary, eds., *Materials and Expertise* (see note 7).

14 See Werrett's forthcoming *Thrifty Science: Making the most of materials in the history of experiment*.

To take the last first, chemical practitioners between 1760-1840 were just as likely to use ready-to-hand objects in adapted spaces as to introduce new and specialized instruments and dedicated spaces for experiment. Adaptibility, bricolage and repair were hallmarks of chemical practice. As Simon Werrett discusses in this volume, many chemical practitioners set up laboratories in their homes where they adapted tea cups, saucers, clay pipes, gun barrels and household furniture to chemical ends.[15] Even Lavoisier, famous for using new and prohibitively expensive instrumentation, sometimes cobbled together experimental set-ups from objects originally intended for other purposes; his epoch-making demonstration of the decomposition of water, for example, featured an adapted gun barrel. In practice, chemistry relied at least as much on adaptation, knowedge of lutes and luting, awareness of the most appropriate amalgam, and artisanal proficiency, as it did on theory.

Considering chemists as innovators, bricoleurs and reparateurs is not only apt because they were sometimes one and sometimes the other. Innovation, bricolage and repair often went hand in hand. As Elena Serrano illustrates in this volume, novel instruments and devices were often hybrid compositions of new and recycled or innovative and mundane components. This was especially the case when novel apparatus were commodified for wider distribution; simplified use and repair were important considerations when designing for a broader public.

This sort of adaptive design and use was often discussed in terms of 'oeconomy'. Manuals on household management or 'domestic oeconomy' circulated since the sixteenth century, promoting a balance between excess and conservation, saving and expense, using the old and investing in the new.[16] This was not only a call for thrifty management for its own sake. Oeconomy was widely taken to cover a broader set of meanings and practices by the mid-eighteenth century. Alongside material and financial considerations, oeconomy spoke to the virtues of order, prudence and moral responsibility.[17] Exploring the meanings and practices associated with the word's contemporary uses reveals how actors at the time framed their understanding of and engagement with the world around them.

15 Simon Werrett, "Recycling in Early Modern Science," *British Journal for the History of Science*, 46 (2013): 627-646.

16 Karen Harvey, *The Little Republic: Masculinity and domestic authority in eighteenth-century Britain* (Oxford: Oxford University Press, 2012).

17 Lissa Roberts, "Practicing Oeconomy During the Second Half of the Long Eighteenth Century: An introduction," *History and Technology* 30 (2014): 133-148.

Whether linked to the human or animal body, private households, the state, nature, or chemistry, oeconomy spoke to the maintenance of a well-balanced order. Often associated with 'improvement', oeconomy pointed to productivity, but never in exclusive terms of maximizing material production and profit. Invariably, it also carried a moral connotation, placing the improvement of agricultural and manufacturing yields in the context of stimulating stewardship of material *and* social resources – whether within the individual, regional or national household.[18] This variously entailed tying educational programs to the goals of cameralist administration; integrating programs of experiment, communication and engagement aimed at public education with the improved production of domestic goods; bringing education and practice together to stimulate the circulation and use of rural waste products and industrial leftovers to further production in both agriculture and manufacturing; and tying educational programs for chemical practitioners to the ideals of good citizenship.[19]

The ideals and practices of oeconomy receded from their once prominent position in European cultural, institutional and political realms by the mid-nineteenth century. It is beyond the bounds of this study to explain why or fully how this occurred. But surely the mismatch between oeconomy's idyllic projections of balance and order and the often disruptive circumstances that marked the years 1760-1840 were involved. War, political upheaval, the growth of manufactures and social displacement constantly challenged the idealized harmonies of enlightened society. Scales of operation were transformed in the armed forces, the civil service, and in industry.[20] While domestic, artisanal modes of production continued, and while agriculture remained the largest employment sector until at least 1850, industrial manufactures grew, urban populations burgeoned and peoples traversed regions and continents *en*

18 Joppe van Driel, "The Filthy and the Fat: Oeconomy, Chemistry and Resource Management in the Age of Revolution," PhD Thesis, University of Twente, 2016.

19 Christophe Meinel, "Reine und angewandte Chemie," *Berichte zur Wissenschaftsgeschichte* 8 (1985): 25-45; Andre Wakefield, "Police Chemistry," *Science in Context* 13 (2000): 231-267; Elena Serrano, "Making Oeconomic People: The Spanish Magazine of Agriculture and Arts for Paris Rectors (1797-1808)," *History and Technology* 30 (2014): 149-176; Joppe van Driel, "Ashes to Ashes: The stewardship of waste and oeconomic cycles of agricultural and industrial improvement, 1750-1800, *History and Technology* 30 (2014): 177-206; Le Roux, "Chemistry and Governance" (see note 6); Lissa Roberts, "P.J. Kasteleyn and the "Oeconomics" of Dutch Chemistry," *Ambix* 53 (2006): 255-272.

20 John Brewer, *The Sinews of Power: War, money and the English state, 1688-1783* (London, 1989); Anna Simmons (this volume) discusses how changes of scale affected chemical production.

masse.[21] The ranks of chemical practitioners, often trained in newly autonomous laboratories, swelled accordingly. Changing scales and approaches to materials, production and governance, were undoubtedly tied up with changing attitudes and practices. The challenge is to explore and understand these connections and their consequences without the taint of teleology.

This requires rethinking the historical relationship between oeconomy and oeconomic practices, on one hand, and interpretive categories drawn from economics and economic history, on the other.[22] Given the performative impact and results of oeconomic formulations and activities, it is misleading to dismiss oeconomy as a cultural conceit of elite amateurs, a doomed project or rhetorical side-show to economic development. Neither was oeconomy a proto-concept that gave way to economic analysis as the latter's concepts matured during the early nineteenth century.[23] Such views move between [1] distinguishing between oeconomy as a cultural expression and economics as expressive of 'real world' activities and [2] isolating oeconomy as a concept and placing it under a larger rubric of economic concepts, which is teleologically structured by a movement toward modern economic organization and understanding. The first privileges economics as reflective of material reality; the second grants it conceptual priority, implying that economic (re-) conceptualization is a key motor of historical change.

This volume refuses both these options, arguing instead for a non-teleological perspective. By the mid-nineteenth century governing attitudes, policies (including colonial policies and taxation regimes) and practices in western Europe instantiated the market, social welfare and nature as distinct realms of conceptualization, activity and governance. But this development – which carved out a space for interacting with material and human resources in strictly calculative terms of economic value, cordoned off from issues of moral or environmental responsibility – was neither inevitable nor the result of a conceptual change. It arose in a historical landscape whose contours evolved over time as humans interacted with specific material substances and objects in various contexts of conceptually and administratively governed production, con-

21 Rondo Cameron, "A New View of European Industrialization," *The Economic History Review* 38 (1985): 1-23, 6.

22 Timothy Mitchell, "Rethinking Economy," *Geoforum* 29 (2008): 1116-1121.

23 Henry Lowood, *Patriotism, Profit, and the Promotion of Science in the German Enlightenment* (New York: Garland Press, 1991); Margaret Schabas and Neil Di Marchi, "Introduction to Oeconomies in the Age of Newton," Margaret Schabas and Neil Di Marchi, eds., *Oeconomies in the Age of Newton. Annual Supplement to History of Political Economy* 35 (2003): 1-13; Margaret Schabas, *The Natural Origins of Economics* (Chicago: University of Chicago Press, 2005), 1-21.

sumption and use – sociomaterial interactions often mediated by chemists and chemistry.[24]

But if historical change is a consequence of sociomaterial interaction, we need to understand what that entails, both in general historiographical and specific historical terms. Contributions to this volume offer a variety of approaches to this subject, as they explore histories of specific materials and material objects between 1760-1840. Lissa Roberts and Joppe van Driel tackle the case of coal in their essay, generally identified as the energy source that fueled the industrial revolution.[25] Demonstrating that coal's identity was actually far from settled at the time, they argue for understanding material identities – and the values associated with them – as historically open rather than ontologically fixed.

Scholars such as Hans-Jörg Rheinberger and Karin Knorr Cetina have made similar claims in their discussions of 'epistemic things' and 'epistemic objects', emphasizing the epistemic openness of objects – but only in the context of experimental investigation.[26] Rheinberger thereby distinguishes between 'epistemic objects' and "stable, technical objects that may define the boundary conditions of further epistemic objects." Knorr-Cetina contrasts the epistemic openness of objects that undergo scientific research with the stability of "commodities, instruments and everyday things."[27]

Simon Werrett's investigation of household chemistry in which ready-to-hand objects were pressed into experimental and productive service problematizes the distinction between research objects' epistemic openness and the stability of 'technical' and 'everyday' objects. Making do with impromptu equipment

24 William Ashworth, "'Between the Trader and the Public': British alcohol standards and the proof of good governance," *Technology and Culture* 42 (2001): 27-50; Joppe van Driel and Lissa Roberts, "Circulating Salts: Chemical governance and the bifurcation of "nature" and "society"," *Eighteenth-Century Studies* 49 (2016): 233-63; Joppe van Driel, "The Filthy and the Fat (see note 18).

25 E.A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: Cambridge University Press, 2010).

26 Hans Jörg Rheinberger, *Toward a History of Epistemic Things* (Palo Alto: Stanford University Press, 1997); Karin Knorr Cetina, "Objectual Practice," T.R. Schatzki, K. Knorr Cetina, & E. von Savigny, eds., *The Practice Turn in Contemporary Theory* (New York: Routledge, 2001), 184-197; Cyrus Mody and Michael Lynch, "Test Objects and other Epistemic Things: A History of a Nanoscale Object," *British Journal for the History of Science* 43 (2010): 423-458.

27 Hans-Jörg Rheinberger, "A Reply to David Bloor: 'Toward a Sociology of Epistemic Things'," *Perspectives on Science* 13 (2005): 406-10, 407; Knorr-Cetina, "Objectual Practice," p. 84 (see note 26).

involved a process of learning about what works. Which materials reacted with experimental substances and were therefore unusable in experimental setups? What was the best way to seal a make-shift container?[28] Roberts and Van Driel's discussion of the history of coal reveals further that the openness of "commodities, instruments and everyday things" is not only epistemic. The identities of materials and material objects are as much a matter of what they do as of what we know about them. But what they can do is neither simply a question of some essential capability or characteristic, nor only of human use. Philosopher Annemarie Mol writes, "[O]ntology is not given in the order of things [...] instead, ontologies are brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices."[29] As represented by Elena Serrano's discussion of 'affordance' in her essay, our goal is to portray material identities and claims of agency in ways that recognize the historical interplay between the specificities of materials and material objects and the contexts in which they were investigated and put to work.[30]

The isolation and identification of qualitatively distinct 'airs' or 'gases' form a central focus of histories of the Chemical Revolution.[31] In her essay, Marie Thébaud-Sorger goes beyond considering them as epistemic objects to the question of how they became manipulable commodities that firmly attached chemistry to both the increasing commodification of society and the spectacles that celebrated this transformation. Substances such as coal and airs also linked chemistry to processes such as urbanization and (initially oeconomic) concerns over public health, which emerged as foci of governance in the period 1760-1840. Aiming to operate at a scale of whole populations, evolving regimes of cleanliness and hygiene, health and security depended on massive material investments and the disciplining of large populations. Key to this process was the construction of urban architectures enabling the circulation of clean air and water and the elimination of foetid smells and poisonous miasmas.[32]

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28 Adele Clarke and Joan Fujimura, eds., *The Right Tools for the Job* (Princeton, NJ: Princeton University Press, 1992).

29 Annemarie Mol, *The Body Multiple: Ontology in medical practice* (Raleigh, NC: Duke University Press, 2002), 6; Ingold, "Materials," p. 1 (see note 8).

30 Affordance refers to "those functional and relational aspects of technology that frame but do not determine the possibilities for action in relation to an object." Brian Rappert, "Technologies, Texts, and Possibilities: A reply to Hutchby," *Sociology* 37 (2003): 565-80, 566.

31 Jan Golinski, "Chemistry," Roy Porter, ed., *The Cambridge History of Science: Volume 4, eighteenth-century science* (Cambridge: Cambridge University Press, 2003), 375-396.

32 Thomas Markus, *Buildings & Power: Freedom and control in the origin of modern building types* (London: Routledge, 1993), 146-158; Christopher Hamlin, "State Medicine in Britain,"

Chemists played a central role in such activities as experts on spa waters and urban water and gas supplies, as overseers of ventilation projects, and through fumigation practices using new chemical substances.[33] Elena Serrano explores one such case, focusing on how newly designed 'fumigating machines' were used to combat disease in France and Spain at the beginning of the nineteenth century. Importantly, these machines simultaneously transported a recently isolated air and new knowledge claims that explained it. They also embodied reformulated modes of governance that, mediated by chemical experts, transferred direct responsibility for public health from government agencies to the individual behavior of citizens who were charged with using such contraptions.[34] But material concerns were as crucial as the role played by chemists. For operating on a transnational scale, as this project did, necessitated adaptation; simplified designs and cheaper materials enabled the machine's mass manufacture.

José Ramon Bertomeu's exploration of arsenic in the 1830s and '40s offers one more example of how focusing on materials exposes the non-teleological co-construction of sociomaterial identities. His essay draws attention to the efforts waged in these decades to identify the notorious poison arsenic. If oeconomy tolerated – or even valued – material ambiguities and open-ended capacities for repurposing and re-use, the economic and social orders emerging by the late 1830s depended on various institutions – manufactories, government laboratories, law courts, public health bureaus – that required specific definitions and identities. Institutional attempts to know and thereby govern materials and their use nonetheless continued to be plagued by ambiguities of material definitions and application. The definition of arsenic, its presence and properties, thus emerged alongside the identities of chemical practitioners, productive sectors, uses and institutions that engaged with it, determining the agency of all the actors involved.

Dorothy Porter, ed., *The History of Public Health and the Modern State* (Amsterdam; Atlanta, GA: Rodolpi, 1994), 132-164.

33 Matthew D. Eddy, "The Sparkling Nectar of Spas; or, mineral water as a medically commodifiable material in the province, 1770-1805," Klein and Spary, eds., *Materials and Expertise*, 283-292 (see note 7); Christopher Hamlin, *A Science of Impurity: Water analysis in nineteenth-century Britain* (Berkeley, CA: University of California Press, 1990); Leslie Tomory, *Progressive Enlightenment: The origins of the gaslight industry, 1780-1820* (London; Cambridge, MA: MIT Press, 2012).

34 Simon Schaffer, "Measuring Virtue: Eudiometry, enlightenment and pneumatic medicine," Andrew Cunningham and Roger French, eds., *The Medical Enlightenment of the Eighteenth Century* (Cambridge: Cambridge University Press, 1990), 281-318.

What, then, was chemistry in the period 1760 to 1840? This section's focus on materials and material objects positions chemistry at the intersection of gradual yet impressive shifts in production, governance and their relationship. Chemistry flourished through its ability to use materials and multiply their varied affordances, but the manifestations, management and meaning of this ability gradually changed. An initially oeconomic orientation associated with household management and its prudent (re-) use of ready-to-hand objects and instruments posited the inseparably social and moral character of material order. By the late 1830s, the sociomaterial challenges of shifting scales and multiplying and increasingly various fruits of chemical production simultaneously fed and responded to efforts to govern them. Now against a view of materials as open-ended and capable of continuous revision, manufacturing – along with various governance practices (often mediated by chemists and chemical 'expertise') that regulated and taxed its materials, processes and products – divided phases of production and consumption, seeking to fix the identity of material objects as commodities. Chemical practitioners operated in a growing number of contexts, assessing the properties of materials and their suitability to manufactures, developing novel products and processes, and providing credit and controls for unfamiliar products. Managing this complex state of affairs increasingly relied on two mutually reinforcing loci of governance. One was situated in the specifying processes of governmental legislation and courtroom adjudication. The other resided in the organization and conceptualization of market oriented practices that translated social and material interplay into calculations and models, masking their multifaceted interactions as they transformed them.

The division of labor and specialization demanded by these processes and their requirement of strict definitions and identities proved a double-edged sword. On one hand they afforded chemistry's growing autonomy, professional identity and recognized expertise. On the other, they narrowed understandings of material and social identities to the point where their complex intersections and mutual constitution seemed to disappear. What remained was a sense not of interpenetrating oeconomies of materials, production and governance, but of separate spheres of agriculture, industry, chemistry, and government. Composing separate historical narratives of these spheres then served to reinforce their boundaries, raising chimerical puzzles over how one influenced the other.

Chemical Governance and the Governance of Chemistry

Our focus on 'chemical governance' might seem odd or anachronistic at first. In current parlance, it is understood either as a form of 'corporate governance', whereby chemical manufacturers assume responsibility for construing and policing their own ethical performance, or related more generally to the management of hazardous chemicals.[35] Almost invariably, chemical governance is currently invoked in relation to the environmental impact of chemicals used in specific industrial contexts. Behind this configuration is a specific – neo-liberal – rationality that calculates 'good' governance in terms of transaction costs, bracketing it off from other relations seen as involving 'externalities' whose consequences might call for governmental response or as extra-governmental concerns best left up to social and corporate organizations or 'the market'.

Michel Foucault and others have called on us to step back and recognize the historical character of this regime whose beginning, they argue, was in the period covered by this volume.[36] Such a move frees us from considering chemical governance – like governance more generally – as formed or constrained by the currently reigning rationality, warranting instead the historicization of its conceptualization and practices. This requires an umbrella definition of chemical governance that stands above the ways in which specific historical regimes framed it. Here we define it as entailing the privately initiated or government sanctioned employment of chemists and their practices to stimulate or inhibit productive activities and manage resources, people, activities, environments, and their relations, in accordance with specific norms and goals. The essays in this volume zero in on the historical specificities of chemical governance and how they evolved during the period 1760-1840.

It helps to recognize that 'governance' was an actors' category during this period. A survey of uses between 1760 and 1840 shows a cluster of related meanings. Governance referred to the duties of governing; that is, the management of a socio-political unit, institution or individual estate, often with a paternal character and directed toward 'improvement'.[37] It spoke to the influence one had over another's life and behavior, but could also involve exercising

35 Henrik Selin, *Global Governance of Hazardous Chemicals: Challenges of multilevel management* (Cambridge: MIT Press, 2010); Lissa Roberts, "Exploring Global History Through the Lens of History of Chemistry: Materials, identities and governance," *History of Science* 54 (2016): 335-361, on 350-356.

36 Michel Foucault, *Naissance de la biopolitique, Cours au Collège de France 1978-1979* (Paris: Gallimard Seuil Haute études, 2004).

37 William Bridle, *A Narrative of the Rise and Progress of the Improvements Effected in His Majesty's Gaol at Ilchester* (Bath: Wood, Cunningham and Smith, 1822).

control over materials; chemists, for example, were said to exercise governance over fire.[38] Finally, by analogy to 'divine governance', it entailed the maintenance of material and social order for the public good.[39]

Attention to chemical governance in this volume highlights the ways in which chemists and chemical practices were integral to a broad range of significant governance processes between 1760 and 1840. Though much more work needs to be done, the biographies of leading figures such as Lavoisier, Guyton de Morveau and Jean-Antoine Chaptal point to how the practices and institutions of chemical knowledge production in France were intertwined with industrial and administrative developments.[40] So too has recent work on 'artisanal-scientific experts' who served throughout Europe as administrative officials, consultants and inspectors for various state agencies involved with the stimulation and management of sectors such as mining, metal production, agriculture, porcelain manufacture and textiles – been helpful on a more international scale.[41]

The essays here identify chemical governance as a practice that goes beyond individual case studies. The essays by Christine Lehman and Thomas Le Roux explore the history of chemical governance in relation to the French state's regulation of chemical industry up to 1830. Through an examination of requests for state support in the production of *céruse* (white lead or compounds containing it), Lehman concentrates on how processes of chemically mediated governance helped steer industrial production, complicating claims about innovation along the way. Far from simply a matter of developing knowledge and practices in a drive to improve the quality, quantity and/or profitability of production, French chemists who served as consultants and administrators found their mediations situated within a complex web of interests. Producers seeking state support might be driven by the desire to protect a manufacturing process, capture a geographically based market or outflank a competitor. The demands of various ministries directed attention toward often-irreconcilable

38 Jean François Clément Morand, *L'Art d'exploiter les mines de charbon de terre* (Paris: Saillant et Nyon, 1768-1779), vol. 2, 1192, 1195, 1255; Basil Valentine, "The Stone of Fire," in Francis Barrett, *The Lives of Alchemystical Philosophers* (London: Macdonald and Son, 1815), 232-236, on 233.

39 *The Book of Common Prayer* (Oxford: T. Wright and S. Gill, 1771).

40 Charles Gillispie, *Science and Polity in France: The revolutionary and Napoleonic years* (Princeton, NJ: Princeton University Press, 2004)

41 Ursula Klein, ed., *Artisanal-Scientific Experts in Eighteenth-Century France and Germany*, special issue of *Annals of Science* 69 (2012): 303-433; Bruno Belhoste, *La Formation d'une technocratie. L'École polytechnique and ses élèves de la Révolution au Second Empire* (Paris: Belin, 2003), esp. 75.

questions of international competition, domestic commerce and social considerations. The state was far from monolithic. The formulation of chemically based advice and administrative decisions was thus always a matter of negotiating between various interests.[42]

Such negotiations, of course, were always situated in specific contexts. The social, political, commercial and financial dislocations associated with the French Revolution and Napoleonic era framed the pursuit of and changes in governance processes in France while highlighting the constitutive role of chemists and chemistry. As Le Roux shows for the formation of regulatory policies and practices concerning the environmental impact of chemical industry there, the abolition of both traditional corporations ranging from artisanal guilds to the *Académie des sciences* and the institutional apparatus responsible for governance during the *ancien régime* framed an intensification of longer-term historical developments that – as Tocqueville first pointed out – were transforming France from a corporate to a modern state.[43] Wartime exigencies and increasing international competition, coupled with domestic dislocation and change, simultaneously intensified demand for the products of chemical industry and a greater need to adjudicate between the operational requirements of industrial production and the public's experience of its environmental consequences. It was in this context that chemists were called upon to help encourage industrial development, as well as to determine and compare the relative values of productivity and public health and welfare.

The determination and comparative measurement of value in relation to the interactive triad of industrial development, public welfare and environmental sustainability were inevitably bound to competing norms and issues of trust that often remained untranslatable into 'objective' numbers.[44] One answer to the persistence of qualitatively heterogeneous issues was provided by the evolution of new analytical categories through which to define, organize and judge chemically construed phenomena.[45] Beyond the development of new nomenclatural and instrumentally mediated practices, Le Roux argues, this entailed reconfiguring the legally sanctioned definitions and boundaries

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42 Timothy Mitchell, *Rule of Experts: Egypt, techno-politics, modernity* (Berkeley: University of California Press, 2002); Lissa Roberts, "Accumulation and Management in Global Historical Perspective: An introduction," *History of Science* 52 (2014): 227-246, 238.

43 Alexis de Tocqueville, *L'Ancien régime et la révolution* (Paris: Michel Lévy Frères, 1856).

44 Theodore Porter, *Trust in Numbers: The pursuit of objectivity in science and public life* (Princeton, NJ: Princeton University Press, 1995).

45 On classification as a form of governance, see Steve Woolgar and Daniel Neyland, *Mundane Governance: Ontology and accountability* (Oxford: Oxford University Press, 2015), 55-77.

between 'harmfulness' and 'harmlessness' – a process in which chemists played a key role. More fundamental still, chemists throughout the period covered by this volume were intimately involved in a process whereby 'the marketplace', 'society' and 'nature' became reified as essentially distinct categories through the very governance practices that were established to police their hybrid interactions.[46]

It needs to be stressed that the history of chemical governance was an open-ended one – neither simply the consequence of a battle of ideologies such as mercantilism or cameralism versus liberalism, nor directed toward any particular teleological end. Rather chemical governance and the effects with which it was associated are best understood by tracing how it evolved out of largely mundane processes. This approach is especially promising for places such as Sweden, Prussia and the Austrian Empire where the state's regulation of mining and industry relied on chemical expertise. A number of recent studies have emphasized the role of 'hybrid experts', who brought a marriage of chemical and bureaucratic training and experience to the performance of their duties.[47] We still need more fine-grained studies of their daily activities, however, to inform longer-term histories of industrialization in these lands. In place of studies that turn to the influence of 'Baconian empiricism', 'Newtonian physics' or 'rationalist inquiry' to explain the transformation of production techniques and sociopolitical institutions, we need accounts that build on the actual work carried out by those who used their chemical knowledge and know-how in their daily practices as mining officials, industry inspectors, excise officers and so forth.[48]

William Ashworth has charted the ways in which mundane instrumentally-mediated regulatory processes carried out by British excise agents worked, not

46 Joppe van Driel and Lissa Roberts, "Circulating Salts" (see note 24); David Wachsmuth, "Three Ecologies: Urban metabolism and the society-nature divide," *The Sociological Quarterly* 53 (2012): 506-523.

47 Ursula Klein, "Savant Officials in the Prussian Mining Administration," *Annals of Science*, Special Issue: *Artisanal-Scientific Experts in Eighteenth and Nineteenth-Century Germany and France*, 69 (2012): 349-374; Peter Konečný, "The Hybrid Expert in the 'Bergstaat': Anton von Ruprecht as a professor of chemistry and mining and as a mining official, 1779-1814," *Annals of Science* 69 (2012): 335-347; Ursula Klein, "The Prussian Mining Official Alexander von Humboldt," *Annals of Science* 69 (2012): 27-68; Hjalmar Fors, "The Knowledge and Skill of Foreigners: Projectors and experts at the early modern Swedish Board of Mines," Hartmut Schleiff and Peter Konečný, eds., *Staat, Bergbau und Bergakademie im 18. und frühen 19. Jahrhundert* (Stuttgart: VSWG, 2012), 53-62.

48 Eric Dorn Brose, *The Politics of Technological Change in Prussia: Out of the shadow of antiquity, 1809-1848* (Princeton, NJ: Princeton University Press, 1993), 13.

only to fix government revenues and establish standards for foodstuffs and alcohol, but also to suggest new products and production processes for distillers and others looking to minimize taxes and maximize profits. In turn, developments in the production and marketing of new products fed the further development of chemical instrumentation and testing for policing the composition and healthfulness of comestibles.[49]

The sort of chemical governance discussed by Ashworth was largely an urban matter. Cities increasingly became sites of chemical concern and governance, as their rising populations engaged in expanding networks of production, exchange and consumption. This brought urban and rural environments into closer contact through the interweaving of agricultural and industrial practices. As discussed by Joppe van Driel, urban elites joined with landowners and government officials in the Netherlands both to encourage and police the collection and circulation of urban wastes for use as agricultural fertilizers, and the return of industrial crops for urban-based manufacturing. This reminds us that chemical governance was not only a governmental affair. It also engaged private individuals who often joined together in oeconomic societies to encourage and monitor 'improvement'.[50]

As cities grew, observers became increasingly aware of the potential to study and need to govern them as chemical systems in their own right. While mediating between the encouragement of industry and the health of urban dwellers exposed to industrial toxins was part of the story, so too were problems such as sewage, water and food supplies, lighting, building supplies and the collection of vital materials such as saltpeter – all candidates for chemical governance.[51] Ernst Homburg has discussed proposals to establish urban chemical police in various German states from the 1820s.[52] Christopher Hamlin has examined the roles played by French and British chemists between 1780 and 1880, as they simultaneously aspired to the position of urban regulators and tied their increasing professional status to industrial consultation. Without a clear identity, he argues, chemists were never able to create "a matter-based science of urban management" as an authoritative tool of governance along the lines of

49 Ashworth, "'Between the Trader" (see note 24); See also the essays in this volume by Elena Serrano and Marie Thébaud-Sorger.

50 Driel, "Ashes to Ashes" (see note 19); Lissa Roberts, "Practicing Oeconomy" (see note 17).

51 André Guillerme, "Enclosing Nature in the City: Supplying light and water to Paris, 1770-1840," *Construction History* 26 (2011): 79-93; Sabine Barles, *L'invention des déchets urbains: France, 1790-1970* (Seyssel: Champ Vallon, 2005).

52 Ernst Homburg, "The Rise of Analytical Chemistry and its Consequences for the Development of the German Chemical Profession, 1780-1860," *Ambix* 46 (1999): 1-32, 19.

architecture and engineering.[53] Instead they remained a mixed community of, at one and the same time, educators, guardians of the public interest and consultants for maximizing industrial profit.

The period 1760-1840 was an age of networks and activity that encompassed the entire globe, often involving the movement of massive quantities of chemical substances and objects, and innumerable possibilities for the exercise of both chemical production and governance.[54] Chemical governance was dispersed across a multitude of practices, techniques and decisions traversing the planet. Such dispersal may be appreciated better by examining a case of the global reach of chemical governance. Andreas Weber examines an episode in the history of imperial Dutch monetary policy in this volume to demonstrate that even something as seemingly abstract as monetary policy was subject to chemical governance. Importantly, his analysis underscores the polycentric character of imperial governance by revealing its mundane dependence on local chemical practitioners and their practices situated both in metropolitan centers and in far-off colonial settings.[55] Beyond their initial pronouncement, policies actually took shape through their embodiment in coins and bank notes – the production of which required locally available chemical expertise. A colonially based assayer and mint master, therefore, could change the direction and consequence of imperial policy by minting coins with an alloy containing more silver than instructed. Rather than simply serving imperial masters, local practitioners harnessed their chemical know-how to colonize the policy-making process by which the empire was supposed to be ruled. Substituting locally determined value calculations for those that originated in The Hague recalibrated the policy they were supposed to pursue, shifting the fulcrum of practical power away from Dutch ministerial designs toward the geographically distant networks to which such values were beneficial.

The point of Weber's analysis is that both imperial policies and the Dutch treasury were affected by the chemically informed acts of individuals operating on the other side of the world. But if chemical practices could alter the course of financial management at the level of national and imperial govern-

53 Hamlin, "The City" (see note 6).

54 Pratik Chakrabarti, "Empire and Alternatives: Swietenia febrifuga and the cinchona substitutes," *Medical History* 54 (2010): 75-94; Gregory Cushman, *Guano and the Opening of the Pacific World: A global ecological history* (Cambridge: Cambridge University Press, 2013).

55 Simon Schaffer, "Golden Means: Assay instruments and the geography of precision in the Guinea Trade," Marie-Noëlle Bourget, Christian Licoppe and H. Otto Sibum, eds., *Instruments, Travel and Science. Itineraries of precision from the seventeenth to the twentieth century* (London: Routledge, 2002), 20-50.

ments, so was financial governance crucial to the development of chemistry at the institutional level. Without the allocation and monitoring of funds to support institutions of learning, for example, the course of chemistry's disciplinary and professional development would have been quite different during this period. Importantly, as Sacha Tomic reveals in his study of financial governance at the Paris École de pharmacie, financial records are more than just a ledger showing income and expenditures. They also bear the imprint of a guiding moral economy under whose regime rewards were calculated in accordance with loyalty and service. Hence could a laboratory assistant rise to the rank of professor, in direct contradiction to current generalizations about 'invisible technicians' and the role their perceived lack of scientific insight played in the achievement of 'mechanical objectivity'.[56]

In sum, if chemistry's practices, practitioners and educational institutions were subject to various acts of regulatory governance, so too were chemists and chemical practices integral to more general processes of governance between 1760 and 1840. Insofar as chemists managed both materials and socially-embedded processes, they could claim to be essential to good governance. Chemistry had long been connected to medicine and the management of individual health. In the eighteenth century, chemists promoted and participated in practices that posited chemistry as an important or essential element in the medical management of communities. As chemical products and contexts of material production, use and disposal proliferated, chemists assumed an increasing number of roles as expert consultants in efforts to govern them. They tested, measured, experimented with and informed legal adjudications of material goods, serving taxation regimes, for example, through the study of adulteration. Such roles were far from straightforward, however, as chemists found themselves inserted into complex negotiations between competing communities and interests. In this context, financial and legal demands overtook oeconomic assessments of social and moral order that had previously been linked to chemical interventions.

Out of these interactions emerged regularly renegotiated policies, regulations, legal judgments, restrictions and codifications. Simultaneously these processes transformed the identities of materials and chemists themselves. Such mundane procedures and routines were also, no doubt, consequential for changing iterations of chemistry, governance and production, which suggests the inadequacy of a narrative that unduly focuses on revolutionary change in this period.

56 Lorraine Daston, "The Moral Economy of Science," *Osiris* 10 (1995): 2-24, 20.

Revisiting the History of Production

Production looms large as a focus in history writing on the period covered by this volume. Often linked to revolution – whether political, scientific or industrial, it is hard to ignore the roles that material and knowledge production have been said to play in historical development. An obvious question for this volume, then, is what can be learned by considering the history of production in conjunction with materiality and governance. In some ways, this approach and the analysis to which it gives rise underscore current historiographical views. While it is still standard to speak of 'the Industrial Revolution', for example, the term is now generally recognized as covering a longer and more gradual process of change. So too have we let go of the belief that industrialization followed a single paradigm.[57] And while economic historians continue to focus on economic growth as the Industrial Revolution's defining characteristic, they have joined with other historians to consider the relations between material and knowledge production; between production, consumption and use; and between production and the environment.[58] This has created ground for raising questions that are only answerable by bringing various historical disciplines together. Especially given the braided connections amongst the environmental, political, social, cultural and economic issues revealed by the complex challenges we currently face, historians find themselves looking to the past in more collaborative, interdiscipinary ways.[59] A central argument of this volume is that the history of chemistry provides a particularly apt vehicle for this sort of collaborative inquiry because its subject matter so patently sits at the intersection of historical engagements through which humans participated in weaving the social, material, political, economic and environmental together.[60]

The essays in this section highlight the interpretive possibilities afforded by bringing historical questions about production together with attention to gov-

57 Jeff Horn, Leonard N. Rosenband and Merritt Roe Smith, *Reconceptualizing the Industrial Revolution* (Cambridge, MA: MIT Press, 2010); Emma Griffin, *A Short History of the Industrial Revolution* (London: Palgrave, 2010).

58 Joel Mokyr, *The Gifts of Athena: Historical origins of the knowledge economy* (Princeton, NJ: Princeton University Press, 2002); Jan de Vries, *Consumer Behavior and the Household Economy, 1650 to the Present* (Cambridge: Cambridge University Press, 2008); E.A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: Cambridge University Press, 2010).

59 Brett Walker speaks of 'hybrid causation'. *Toxic Archipelago: A history of industrial disease in Japan* (Seattle: University of Washington Press, 2010).

60 Lissa Roberts, "Producing (in) Europe and Asia, 1750-1850," *Isis* 106 (2015): 857-865.

ernance and materials. Among other things, this approach underscores that 'production' is not simply a synonym for industry, translatable into measurable economic indicators. Along with material goods, producers make, use and consume knowledge, culture and political goods. The relations amongst all these elements require investigation.[61] Accordingly, Bernadette Bensaude-Vincent and Frank James examine the various ways in which governance mediated between the supposedly distinct realms of knowledge production and social order, bringing the core message of *Leviathan and the Air Pump* to life: "Solutions to the problem of knowledge are solutions to the problem of social order."[62] Anna Simmons and John Christie explore production in the context of urban manufacturing sites, affording an understanding of production sites as complex points of intersection between local and global translations involving the interaction of humans and materials with layered regimes of governance and production processes. Finally, Robert Anderson investigates interactions between academic chemists and those directly engaged in chemical industry to reflect on how we ought to understand the historical relationship between material and knowledge production. Here again we find general claims giving way to the specificities of local situations.

Though the period investigated in this volume is sometimes referred to as 'the age of revolution', debate continues regarding its 'revolutionary' nature.[63] Definitions of the Industrial and Chemical Revolutions have changed with generational regularity.[64] And while no one doubts that political revolution took place in France in 1789, discussions continue regarding its cause and character, including its relationship with Enlightenment ideas, industrialization and scientific developments.[65] The links between science and society in revolutionary France have traditionally been discussed either by chronicling how the state recruited scientists to perform specific tasks and reform productive sectors or as an aspect of intellectual history.[66] In her analysis of pedagogical

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61 Roberts, "Producing" (see note 60).

62 Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the experimental life* (Princeton, NJ: Princeton University Press, 1985), 332.

63 Hobsbawm, *Age of Revolution* (see note 1).

64 David Cannadine, "The Present and the Past in the English Industrial Revolution, 1880-1980," *Past and Present* 103 (1984): 131-172; McEvoy, *Historiography* (see note 9).

65 Robert Darnton, *The Forbidden Bestsellers of Pre-Revolutionary France* (New York: W.W. Norton and Co., 1996); idem., *Mesmerism and the End of the Enlightenment in France* (Cambridge, MA: Harvard University Press, 1968); Jeff Horn, *The Path Not Taken: French industrialization in the age of revolution, 1750-1830* (Cambridge, MA: MIT Press, 2006).

66 Gillispie, *Science and Polity* (see note 40); W.R. Albury, "The Order of Ideas: Condillac's method of analysis as a political instrument in the French Revolution," John Schuster and

reform at the École normale, Bensaude-Vincent looks instead at the kinds of mediation proposed to realize translations between "the problem of knowledge" and "the social order."

The establishment of the *École normale* in 1794, she reminds us, was part of a broader program to 'normalize' France. Alongside training teachers to teach a standard curriculum across France, a unified system of weights and measures was meant to normalize market exchanges throughout the country – itself administratively normalized through its division into *departements*.[67] The pedagogical structure that informed teacher education at the *école* built on Condillac's analytical approach, an instrument for standardizing understanding by eradicating lapses of logic and knowledge. Lavoisier had drawn on Condillac in his *Traité élémentaire de chimie*.[68] Disciplining chemistry, as advocated by Lavoisier, was seen by the school's organizers as a model for disciplining education more generally and, through that, disciplining the minds and bodies of normalized French citizens.

In fact, the ideal of standardization proved historically problematic. The metric system's introduction met so many local challenges that Napoleon withdrew it; it was finally instituted in 1837. Professors at the *École normale* resisted standardization, generally choosing instead to stress the details of their own disciplines. Charged to teach chemistry, Lavoisier's close associate Berthollet went further, opposing the approach he was supposed to defend. Where Lavoisier had claimed a seamless relation between properly disciplined understanding and the order of nature, Berthollet professed a complex topography of local circumstances and exceptions to rules that could only be governed through careful attention. Teaching (how to teach) chemistry was thereby not a question of normalization, but of training students to produce and apply knowledge in particular situations. In place of the unatainable dream of revolutionary transformation, he argued, an attentive and informed citizenry could thus work to reform the production of knowledge and society in more nuanced ways.

Berthollet was certainly not alone in criticizing the dream of organizing science and society through the unmediated application of abstract principles. But it is one thing to recognize a mismatch between revolutionary ideals and

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R.R. Yeo, eds., *The Politics and Rhetoric of Scientific Method: Historical studies* (Dordrecht: Reidel Publishing Co., 1986), 203-225; Keith Michael Baker, *Condorcet: From natural philosophy to social mathematics* (Chicago: University of Chicago Press, 1974).

67 Ken Alder, "A Revolution to Measure: The Political Economy of the Metric System in France," M. Norton Wise, ed., *The Values of Precision* (Princeton, NJ: Princeton University Press, 1995), 39-71.

68 Antoine Laurent Lavoisier, "Discours préliminaire," *Traité élémentaire de chimie* (Paris: Chez Cuchet, 1789), v-xxi.

the complex variations of local circumstances, and quite another to foresee how governance regimes would actually take shape. As stressed throughout this volume, tensions amongst various interests engaged in the production of knowledge, goods and social order often led to situations that emphasized divisions rather than the applicability of universal principles. Disciplinary programs fed both the professionalization of and distinctions between individual sciences, while attempts to mediate amongst various social, political and economic interests from the standpoint of scientific knowledge often proved illusory – leading to hung juries and recriminations against (members of) the scientific community.[69] Current debates surrounding human and environmental health show how the challenges of governing translations between 'problems of knowledge' and 'social order' remain a key concern.[70]

While the revolutionary context of French attempts to engineer a clean fit between knowledge production and social order through specific governance practices set the question of their relations in sharp relief, examining the situation in Great Britain invites us to consider cases of this historical process in a less dramatic context. Given the growing importance and visibility of laboratories as the nineteenth century progressed, James' contribution to this volume, which follows the chemist Humphry Davy's tenure at two institutionally-based research laboratories in the late 1790s and early 1800s, provides a telling introduction to what followed. James' approach answers historian Graeme Gooday's call to consider laboratories in relation to the broader social worlds they inhabited: as situated between those who provided funding and institutional support, and the public, which varyingly acknowledged their status as sites of knowledge production and authority.[71] In fact, this was a fluid situation, manifesting as many variations as did laboratories themselves. A laboratory, for example, might double as a kitchen whose domestic situation complicated the gendered nature of the relation between science and the social order.[72] So too were laboratories attached to enterprises and institutions whose briefs tied knowledge production to specific purposes, such as the advancement of manufacturing, treating patients or public education.

69 In this volume, see essays by Thomas Le Roux, José Ramón Bertomeu Sánchez, and Lissa Roberts and Joppe van Driel.

70 Naomi Oreskes and Erik Conway, *Merchants of Doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming* (London: Bloomsbury Press, 2010).

71 Graeme Gooday, "Placing or Replacing the Laboratory in the History of Science?" *Isis* 99 (2008): 783-795.

72 Anita Guerrini, "The Ghastly Kitchen," *History of Science* 54 (2016): 71-97; Simon Werrett, "Household Oeconomy," this volume.

As indicated by Sacha Tomic in this volume, laboratories that relied on external funding had also to reckon with an accompanying regime of financial governance. This did not mean, however, that researchers were unable to exercise independence, either in terms of their research or of maneouvering between their sponsors' desires and public approbation. James presents Davy as an entrepreneurial figure who forged his career by creatively courting both patrons and the public's politer echelons, using financial and institutional support to gain a measure of autonomy for his research, which he presented publicly in ways that reinforced his and his findings' authority. That he anchored his efforts in laboratory settings is significant. Unlike modern definitions that emphasize laboratories' scientific character, the word 'laboratory' traditionally indicated a place where raw materials were 'elaborated' – worked upon to produce medicines, chemical substances, or other substances that could be put to use. Like many of his contemporaries, Davy applied the term to nature itself.[73] And in his public lectures at the Royal Institution, he drew on the claimed continuity between nature and his laboratory work to argue for public acceptance of a particular social order. Unlike his mentor Beddoes and outspoken figures such as Joseph Priestley, who championed the egalitarian ideals of radical politics and knowledge-based progress, Davy recruited nature and its investigation in a bid to privilege social stability over equality.[74]

Bringing James' thesis together with historian Jan Golinski's analysis of science as public culture in early nineteenth-century Great Britain, underscores the coincidence of an evolving regime of research autonomy – a professed characteristic of modern science – and the rise of a modern culture of 'public science' in which 'the public' was configured as a passive audience that bowed before scientific authority.[75] We might see this as part of a larger and longer transition in which science and industry became increasingly professionalized. Whatever the realities of domestic participation and use, members of

73 Gooday, "Placing or Replacing," p. 788 (see note 71); Humphry Davy, *Elements of Agricultural Chemistry, or a course of lectures for the Board of Agriculture* (London: Longman, Hurst, Rees, Orme and Brown, 1813), 14; David Gooding, "'In Nature's School': Faraday as an experimentalist," David Gooding and Frank James, eds., *Faraday Rediscovered; Essays on the life and work of Michael Faraday, 1791-1867* (London: Macmillan, 1985), 105-136.

74 Jan Golinski, *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760-1820* (Cambridge: Cambridge University Press, 1992), 197.

75 Ibid.; Thomas F. Gieryn, "Boundary-Work and the Demarcation of Science from Non-Science: Strains and interests in professional ideologies of scientists," *American Sociological Review* 48 (1983): 781-795; Roger Cooter and Stephen Pumfrey, "Separate Spheres and Public Places: Reflections on the history of science popularization and science in popular culture," *History of Science* 32 (1994): 237-267.

the public were being configured as passive consumers of both knowledge and material goods made by others.[76]

The essays in this section highlight the need to recognize multiple geographies, overlapping jurisdictions and evolving identities as intrinsic to historical development. How do we reconcile narratives that stress the importance of locally available materials such as coal or wool with those that follow the movements of substances such as copper, barilla and mercury across the globe or between productive sectors? We often read that English coal powered an eclipse of Indian cotton and other foreign goods in the context of receding government intervention.[77] But other stories can be told that stress the locally heterogeneous character of industrialization.[78] Simmons' examination of pharmaceutical manufacturing in London illustrates the far-flung routes along which pharmaceutically relevant substances traveled. She simultaneously emphasizes the evolutionary character of local production processes that combined incoming substances with locally available resources under corporate and governmental oversight. Governance did more than guide behavior; it played an active role in shaping production, its components and outcomes. As demonstrated by William Ashworth, governance included identifying substances, testing for their 'purity' and composition, and making them serve purposes ranging from revenue enhancement and international competition to public health and welfare.[79]

Historical surveys of industrial production during this period generally highlight mechanization, innovation and the introduction of steam power. But London – like other industrial centers – also housed productive sectors whose sites and methods depended on more and other things than the revolutionary introduction of path-breaking machines. The pharmaceutical sector is a telling example, as it encompassed international trading companies, large-scale wholesale manufacturers and smaller-scale apothecaries and druggists, globally sourced substances and the equipment, knowledge and skill needed to produce, store and sell its products. Its market brought suppliers together with users ranging from individual customers to the mammoth British Navy and East India Company. In turn, its manufacturing sector responded to the inter-

76 John Brewer and Roy Porter, *Consumption and the World of Goods* (New York: Routledge, 1993).

77 E.A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: Cambridge University Press, 2010).

78 Thomas Misa, *From Leonardo to the Internet: Technology and culture from the Renaissance to the present* (Baltimore: Johns Hopkins University Press, 2004), 59-96.

79 Ashworth, "'Between the Trader" (see note 24).

active dynamics within and between supply and demand, mediated by the governance of firms and institutions, as well as regulations imposed by the state as its agents sought to generate revenues, oversee trade, monitor production and protect consumers.

Two resulting trends are especially worth noting. The first has to do with increasing reliance on keeping production and account records, akin to what Ursula Klein calls "paper tools".[80] As much as the chemical formulae on which Klein focuses, bookkeeping records formulized a means to manage humans, substances, laboratory hardware and the processes in which they were mutually engaged with productive effect. This growing reliance on governance through paper was especially welcome in conjunction with a second trend whereby chemical manufacturers met growing demand: expanding premises and upscaling production techniques. Because such moves required increased capitalization, producers who enjoyed privileges and prestige, or whose pharmaceutical skills and connections were matched by business savvy, were at an advantage.

Upscaling also relied on hard-won knowledge, know-how and adaptive hardware, as well as negotiations with government regulators and neighbors who faced increased nuisances. Because chemical production relied on the 'governance of fire', for example, knowledge of heat and its regulation at different scales were key components of this process.[81] Along with having to construct larger furnaces that provided constant and manageable heat, it was necessary to revamp instrumentation to allow continued access to substances while responding to problems and risks that emerged in large scale production. At this level, fumes that were slightly bothersome in small concentrations, for example, manifested a poisonous presence requiring containment.[82] Material production was thus generative of problems of chemical governance. But upscaling also afforded opportunities that deserve more coordinated investigation. Increasing production yielded both sellable products and material remains, which stimulated the utilization of industrial leftovers to achieve

80 Ursula Klein, *Experiments, Models, Paper Tools: Cultures of organic chemistry in the nineteenth century* (Palo Alto: Stanford University Press, 2002); Simon Schaffer, "'The Charter'd Thames': Naval architecture and experimental spaces in Georgian Britain," Lissa Roberts, Simon Schaffer and Peter Dear, eds., *The Mindful Hand: Inquiry and invention from the late Renaissance to early industrialisation* (Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2007), 279-305.

81 See Marie Thébaud-Sorger's essay in this volume.

82 Carleton Perrin, "Of Theory Shifts and Industrial Innovations: The relations of J.A.C. Chaptal and A.L. Lavoisier," *Annals of Science* 43 (1986): 511-542, 530.

product diversification.[83] Examining individual examples provides clues for how to write a longer term history of circular economies that brings technical details together with the various types of material, entrepreneurial and governance practices that stimulated, managed and opposed them.[84]

The picture this all paints might appear path breaking and progress oriented when selectively viewed from the present, but its local ambiguities deserve closer scrutiny. John Christie answers this call in his study of entrepreneurship in industrial Glasgow. Historians variously treat 'the entrepreneur' as an important figure during our period, generally casting entrepreneurship as involving the pursuit of innovation and powering "creative destruction".[85] Historical actors, however, defined the word 'entrepreneur' differently. They were silent about the link between entrepreneurs and innovation and justifiably ambivalent about whether innovation was necessarily a good thing.[86] As Christie shows, the road to success was not always paved by novelty and innovation.

This is not to say that chemical industry witnessed no innovation between 1760 and 1840, but that the contexts and processes that marked its development were too heterogeneous to fit under a single rubric of revolutionary change. It is by delving into the biographies of Glasgow's foremost industrial entrepreneurs that Christie brings industrialization's historical variegation to the fore. Chemical industry between 1760 and 1840 included a highly diverse set of enterprises. Increasingly typical of industrializing cities at this time, Glasgow housed businesses ranging from producers of chemical substances used in other industries to those whose manufacturing processes depended on chemical practices. These businesses also varied in terms of their overall

83 Timothy Cooper, "Peter Lund Simmonds and the Political Ecology of Waste Utilization in Victorian Britain," *Technology and Culture* 52 (2011): 21-44. For examples, see John Graham Smith, *The Origins and Early Development of the Heavy Chemical Industry in France* (Oxford: Clarendon Press, 1979).

84 Telling examples include the Javel factory, south of Paris, and the chemical factory run by Watse Gerritsma in the north Dutch province of Friesland. For details, see Smith, *The Origins* (see note 83); Driel and Roberts, "Circulating Salt" (see note 24).

85 Joseph Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper, 2008), 83; Joel Mokyr, ""Entrepreneurship in the Industrial Revolution," David Landes, Joel Mokyr and William Baumol, eds., *The Invention of Enterprise* (Princeton, NJ: Princeton University Press, 2012), 183-210; Oliver Mallett, "Contesting the History of Enterprise and Entrepreneurship," *Work, Employment and Society* 29 (2015): 177-182.

86 *Dictionnaire universel de commerce* (Paris: Estienne et Fils, 1748), vol. II, 1051. Jean Baptiste Say, *A Treatise on Political Economy; Or the production, distribution and consumption of wealth*, trans. with notes by C.R. Prinsep (Philadelphia: Grigg and Elliot, 1834), 82, note 1; Barbara Cassin, ed., *Dictionary of Untranslatables: A philosophical lexicon* (Princeton, NJ: Princeton University Press, 2014), 265-268.

production strategies and the processes and products found within each. The range of strategies a single firm might employ can be mapped according to five categories: adaptive maintenance of traditional techniques, tools and 'furniture'; upscaling; introduction of new chemical techniques; mechanization; product diversification. In such complex environments, innovation emerges as a contextually bound and relative term – indicative, perhaps, of a change of scale, a revamped instrument, the adaptive introduction of a process or substance used elsewhere, or the use of material leftovers to produce other goods. It was never clear from the start which strategy would work. What is certain is that innovation guaranteed nothing. Neither did knowledge and experience guarantee success. It could take years before a novel machine or process was sufficiently stabilized to be effective, while ambient conditions including government regulations, competition for materials, fluctuating demand and international conflict could derail the best laid plans.

One thing that many industrial endeavors did share was pollution, though its effects were not experienced evenly. Wealthy elites inhabited the greener quarters of urban areas and could more easily escape the city's chemically laden, foul atmosphere. The poor had fewer choices.[87] Chemical industry took place, then, in a context marked by sociomaterial hybridity and inequality. Still true today, chemical production came with greater cost to some and greater profit for others.[88]

A final issue that needs addressing is the historical relationship between material and knowledge production. A longstanding concern amongst historians, the question has been especially highlighted by economic historian Joel Mokyr. Interested to account for British and Western European economic trends and their 'great divergence' with China since the the late eighteenth century, Mokyr dismisses explanations based on the availability of coal and colonies in favor of a 'cultural' argument that emphasizes what he sees as a coincidence between political liberalization and the increasingly pervasive production and application of 'useful knowledge'.[89] While discussions of the

87 Allan Potofsky, "Recycling the City: Paris, 1760s-1800," Ariane Fennetaux, Amélie Junqua and Sophie Vasset, eds., *The Afterlife of Used Things: Recycling in the long eighteenth century* (New York: Routledge, 2015), 71-88, on 75.

88 Andreas Malm and Alf Hornborg, "The Geology of Mankind? A critique of the Anthropocene narrative," *The Anthropocene Review* 1 (2014): 62-69.

89 Mokyr, *Gifts of Athena* (see note 58); idem., *The Enlightened Economy: An economic history of Britain, 1700-1850* (New Haven: Yale University Press, 2009); Kenneth Pomeranz, *The Great Divergence: China, Europe and the making of the modern world economy* (Princeton, NJ: Princeton University Press, 2000).

continued role of state intervention and governance regimes in Great Britain and the continent, as well as of the unmissable contribution of colonial resources and slave labor to European wealth and wellbeing, should be sufficient to put his more contentious claims to rest, the relationship between material and knowledge production to which he draws attention remains crucial.[90] As argued in this volume, focusing on the history of chemistry provides an especially revelatory lens through which to capture their historical relationship.

The primary reason is that hybrid engagement with material and knowledge production was often standard chemical practice. Ursula Klein argues that this justifies considering eighteenth-century chemistry as a "technoscience *avant la lettre*".[91] In his essay for this volume, Robert Anderson asks whether her claim should be generalized for all of Europe and answers by demonstrating that the relationship between science and industry was as much a question of social identities as of knowledge content.

Scotland provides a particularly interesting setting for Anderson's inquiry. Its universities were more open and flexible than many other European institutions during the eighteenth century, which swelled student attendance. By the 1740s the medical faculty at University of Edinburgh, where chemistry was taught, became the most popular in Europe. Simultaneously, as outlined by Christie in this volume, Glasgow, Dundee and other areas became centers for Scotland's burgeoning chemical industry. Chemistry professors found themselves teaching both medical students and those oriented toward manufacture, agriculture and law. Extended acquaintance with applicable knowledge and networks of former students who asked for advice as manufacturers, landowners, policy makers and administrators, meant that academic chemists had to consider their public identities. Joseph Black, chemistry professor at Glasgow and Edinburgh Universities for over forty years, engaged in consulting throughout his career, but insisted on keeping chemistry's social identity as a science distinct from the industrial realm. Contrariwise, Andrew Ure, professor at the Andersonian Institution (1804-1830), happily opted for a hybrid public identity, increasingly supplementing his lectures with publicized work as a popular author and industrial consultant. Quite apart from the question of anachronism, Anderson concludes, not all chemists would have accepted the identity of technoscientists.

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90 Brewer, *Sinews of Power* (see note 20); William Ashworth, "The Ghost of Rostow: Science, culture and the British Industrial Revolution," *History of Science* 46 (2008): 250-274.

91 Ursula Klein, "Technoscience *avant la lettre*," *Perspectives on Science* 13 (2005): 226-266.

In sum, focusing on chemistry, materials and governance offers fresh perspectives on material and knowledge production in the period 1760 to 1840. A picture emerges of gradual, open-ended transformations in which various local circumstances and practices contributed to change. Alongside the new and shiny, which often disappointed, more traditional and mundane processes could make all the difference. Diverse strategies shaped production, from upscaling, administration with "paper tools" and diversification, to the maintenance and adaptation of existing practices. Chemical practitioners engaged with these strategies in various ways, overseeing global circulations of chemical goods, scaling up manufacturing processes, exploiting byproducts, generating and regulating waste and pollution. No doubt aspects of these activities were innovative, but they were integrated in processes of gradual change and long-term development, the results of which were never fully predictable.

Situating Chemistry

As a collaborative effort, the geographical focus of this volume might not be as broad as one would wish. Both Sweden and the German lands, for example, housed important centers of chemical education and activity whose content and contours were closely tied to ambient political, economic and sociomaterial conditions.[92] Chemistry, in fact, played a variety of important roles around the world between 1760 – 1840, whether informing agricultural improvement in the young American republic, producing textiles and luxury goods in Asia or engaging with pharmaceutical substances and metals in Latin America. Examining developments in all these regions through the approach of this volume would add greatly to our understanding of what is, after all, a transnational subject.

But such a huge undertaking has to begin somewhere, and the narrower focus of this volume makes sense, given that France and Great Britain (our essays' primary locations) have long been the dominant foci of attention in connection with the revolutions (the French, Industrial and Chemical) with which this period is most commonly identified. The cases presented here,

92 Anders Lundgren, "The New Chemistry in Sweden: The debate that wasn't," *Osiris* 4 (1988): 146-168; Ernst Homburg, "The Rise of Analytical Chemistry and its Consequences for the Development of the German Chemical Profession (1780-1860)," *Ambix* 46 (1999): 1-32; Hans Erich Bödeker, "Economic Societies in Germany, 1760-1820: Organization, social structures and fields of activities, " Koen Stapelbroek and Jani Marjanen, eds., *The Rise of Economic Societies in the Eighteenth Century* (London: Palgrave MacMillan, 2012), 182-211.

some of which underline the global networks in which chemical substances and practices were enmeshed, invite us to direct our attention away from the monumental, essentially distinct breaks implied by organizing historical analysis according to separate political, industrial and scientific revolutions. Instead, by considering often quotidian histories of material and knowledge production in concert with human interactions with material substances and objects and governance practices that managed productivity and social order, we point to a more unified fabric of historical development: one in which intertwined activities inductively manifested themselves in terms of a package deal of longer-term political, social, industrial and environmental changes.

This hybrid approach fits with current historiographical trends, but is rooted in the very history this volume presents. If we return to the early 1840s, we find the chemist Justus Liebig reviewing chemistry's situation in similar terms to those discussed here.[93] Among other things, he discussed the chain of events whereby the introduction in Great Britain of new bleaching techniques (themselves based on using a previously ignored by-product of soda manufacture) rendered unnecessary the employment of large tracts of rural land as bleaching fields.[94] This freed up both industrial capital for investment elsewhere and land for agricultural exploitation, the latter of which could be enriched with fertilizers that – again, thanks to productive chemical practices – combined urban and rural based waste products.

Liebig described this "as affording an excellent illustration of the dependence of the various branches of human industry and commerce upon each other, and their relation to chemistry."[95] But he and those who read his work did not simply celebrate this as unequivocal evidence of innovation-based progress. Karl Marx, for example, drew on Liebig's discussion of such hybrid chains of knowledge and material production to connect the past with concerns for the future. The sociomaterial 'metabolic system' in which these urban-rural links evolved, Marx recognized Liebig to say, was being unbalanced by capitalist production on an increasingly global scale. In place of previous oeconomic visions of sociomaterial improvement, Marx and others described a chemically mediated process of growing alienation between the

93 Justus Liebig, "Der Zustand der Chemie in Österreich," *Annalen der Pharmacie* 25 (1838): 339-347; idem., "Der Zustand der Chemie in Preussen," *Annalen der Chemie und der Pharmacie* 34 (1840):97-136; idem., *Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie* (Braunschweig: Vieweg, 1840); idem., *Familiar Letters on Chemistry* (London: Taylor and Walton, 1843).

94 Liebig, *Familiar Letters*, pp. 37-38 (see note 93).

95 Ibid., p. 31.

operative sources of production and those who saw to their managed exploitation. It was in such a context of growing antagonism that talk of 'revolution' – industrial or otherwise – gained increasing parlance.[96] A closer acquaintance with the history of chemistry that preceded such utterances can help us reconnect with the continuities and evolutionary developments overshadowed by declarations of revolution.

96 Karl Marx, *Das Kapital* (Hamburg: Otto Meisner, 1867), vol. 1, part 4, chapter 13, pp. 527-530; Victor Hugo, *Les misérables*, authorized English translation, vol. 3 (London: Hurst and Blackett, 1862), 231-233; John Bellamy Foster, "Marx's Theory of Metabolic Rift: Classical foundations for environmental sociology," *American Journal of Sociology* 105 (1999): 366-405.

PART 1

Materials and Material Objects