Sturm und Dung: Justus von Liebig and the Chemistry of Agriculture

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In August of 1990, I completed a PhD dissertation titled "Sturm und Dung: Justus von Liebig and the Chemistry of Agriculture"[1] as a graduate student with the Program in the History and Philosophy of Science and Technology at Cornell University. In this work, I tried to utilize the historical tools I had learned from the members my doctoral committee, Chaired by Professor Dr. L. Pearce Williams; the other two members of my committee were Professor Dr. Isabel V. Hull and Professor Dr. Margaret W. Rossiter. Briefly, these tools included: a thorough mastery of the secondary literature; utilization of primary and manuscript sources, especially manuscript sources neglected by previous historians; and "a radical critique of central institutions and sacred cows" achieved, in part, through "focussing on eccentricity and contradiction."[2] As mentors for my life and models[3] for my work, I thank Professors Williams, Hull, and Rossiter, and apologize for my shortcomings as their student.

I have published a few articles cannibalized from my dissertation.[4] Since I now am fortunate enough to work with an institution that emphasizes teaching over the publication of obscure books, I have never been pressured to publish my dissertation as such. Based on my correspondence and rare attendance at professional meetings, I thought my work on Liebig had been received lukewarmly at best. It therefore came as a great surprise when, because of my dissertation, I received one of the two 1994 Liebig-Wöhler-Freundschafts Preise sponsored by Wilhelm Lewicki and awarded by the Göttinger Chemische Gesellschaft.

My dissertation is about the chemistry of agriculture developed by the Hessen chemist Justus von Liebig (1803-73). Liebig published a small book in 1840, *Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie*. His primary thesis was that plants do not feed on humus, a hydrocarbon produced from decaying plant and animal matter; rather, they feed exclusively on "mineral," i.e. inorganic, compounds such as water, carbon dioxide, and ammonia. Though Liebig's original intent, I think, was to widen the domain of organic chemistry, the successes and controversies engendered by this book led him away from this original intent, and toward chemistry as a central science for agricultural and (later) social and political reform.

Metaphysical considerations also played an important role in Liebig's work. Though, as a good Cartesian, he tended toward mechanism and reductionism,

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Liebig was rather conservative politically and always fearful of losing his socio-economic status.

As a biographer, I have tried to come to terms with Liebig, the man, as well as Liebig, the scientist. Two primary works provided great insight into this task: Kleinert's reveals that, in addition to promoting his own reputation and various programs, Liebig anonymously supported radical social and political views, such as those of Ludwig Büchner (1824-99).[5] Brock's reveals an uglier side, whereby Liebig tried to corner the market on a pseudo-quinine which he fraudulently represented as equivalent to the real thing.[6] These works dispel any naive views one might have regarding a necessary connection between the idealized values of science (rationality, objectivity, honesty) and the actual values of individual scientists.

Social Climbing through chemistry: Justus Liebig's rise from the niederer Mittelstand to the Bildungsbürgertum

Jakob Volhard's biography of Liebig[7] is often taken as the final authority on Liebig. Our contemporary view of Liebig is still heavily colored by Volhard's concerns about a great scientist's place in society, and by his need to glorify chemistry's place in the Imperial German Reich. Yet Liebig's life and education differ considerably from the strange blend of Biedermaier fantasy with Horatio Alger/Samuel Smiles epic that has come to be accepted as standard.

Justus Liebig was born to a poor shopkeeper, had seven brothers and sisters, and was raised in the poor state of Hessen-Darmstadt during the very difficult times of the Napoleonic and post-Napoleonic period. He had to leave his apprenticeship as an apothecary because his father could not pay the required fee. After two years working with the family business, he studied chemistry with K. W. G. Kastner (1783-1857) at the universities in Bonn and Erlangen. In working with Kastner, Liebig experienced what Caneva calls "a crystallization of meaning:"[8] Liebig realized chemistry as a ladder to social and economic advancement at a time when, politically, opportunity was very limited for those from the lower rungs of society. As a part of this crystallization, he realized two other important principles: chemistry must be a carrot on a stick for economic growth; he must be clever in manipulating relationships with others. This latter point cannot be overemphasized: whether through his homosocial/homosexual relationship with the poet Platen or his purchase of a PhD in absentia without writing a dissertation, Liebig proved himself as adept at social intrigue as at chemistry.[9]

Liebig's success, then, as a student of Gay-Lussac (1778-1850) in Paris was based on his ability to manipulate both the chemical and social world. It is noteworthy that Liebig studied in Paris rather than, say, in Berlin or Vienna,

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because of the close relationship between the Rhineland states and France. In 1824, at the age of just twenty-one, Liebig accepted a position in his native land, at the state university in Giessen. As a member of the Bildungsbürgertum, he was in a good position to take advantage of every opportunity presented by the rapid social and economic changes sweeping through nineteenth century Germany.

Liebig and the Development of Organic Chemistry, 1824-40

To provide some continuity for the main course of Liebig's work from 1824 to 1840, and for the connection of this work with his application of chemical principles to plant physiology, I must first criticize the received view of Liebig. Narrow fascination with Liebig's "Research School" has obscured a considerable portion of his influence on industry and society. Authors such as Morrell and Fruton have employed a narrow conception of research school, depended heavily on secondary sources, and generally overemphasized the role of Liebig's research school in the context of his times. Certainly, about one-fifth of Liebig's students did pursue problems in organic chemistry suggested and directed by Liebig. Many of Liebig's other students went off to industry and government, and played instrumental roles in promoting Liebig's ideas. These "others" are just as important in our explanation of Liebig's work as are the one-fifth who met some anachronistic ideal of "research chemist."

Liebig's work during this period reflects the diversity found among his students. He developed a reliable and facile method of performing organic analyses that made his laboratory a factory for producing the chemical formulae of compounds. He extended his influence throughout the chemical community, through friendships with cohorts such as Friedrich Wöhler (1800-82) and establishment figures such as J. J. Berzelius (1779-1848). Through his collaboration with the co-editor of the *Annalen der Pharmacie*, Phillip Lorenz Geiger (1785-1836), Liebig guaranteed the publication of his own and his students' papers, and built a platform for criticizing and directing the development of chemistry. He also extended the influence of chemistry as an authoritative solution to practical problems, as in his role in the establishment and operation of the state-owned manufactory for Epsom Salts and hydrochloric acid at Salzhausen, his involvement in an Aktiengesellschaft to establish a beet sugar refinery in Hessen-Darmstadt, and his efforts to reform pharmacy and physiology.

Thus, during the late 1830s, Liebig's vision for chemistry superseded the practical instruction he offered on the subject. His program for organic synthesis, in particular, fired the imagination of chemists for a century to come and led directly to his work on plant and animal physiology in the 1840s. As the novelist Thomas Pynchon has written:

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Liebig himself seems to have occupied the role of a gate, or sorting-demon such as his younger contemporary Clerk Maxwell once proposed, helping to concentrate energy into one favored room of the creation at the expense of everything else ... "we had been given certain molecules, certain combinations and not others ... we used what we found in Nature, unquestioning, shamefully perhaps but the Serpent whispered, 'They can be changed, and new molecules assembled from the debris of the given ...'"[10]

The Foreground to Liebig's Chemistry of Agriculture

In the first half of the nineteenth century, the many German states held two things in common: the German language and an agricultural economy. Yet the great estates of Mecklenburg were as different from the family farms of Bavaria as were the local dialects, Plattdeutsch and Bayrisch. Throughout Germany, the social, political, and economic events of the Vormärz era left the ground fertile for scientific agricultural reforms. Population growth, the so-called Bauernbefreiung, a lucrative export market for agricultural products, and expectations for the utility of science: all contributed to preparing the ground for the seeds of change. Though Liebig seemed blissfully unaware of both contemporary socio-political events and agricultural reforms when he entered the field of agricultural chemistry in 1840, both are important for understanding the reception of Liebig's work.

Liebig's Vaterland Hessen-Darmstadt is a good example the care a historian must use in defining the particularity and uniqueness of the German states during this era. Even compared with other states in the "third Germany" (i.e. the Rhineland), Hessen-Darmstadt was set apart by differences such as the heavy French influence, which was especially evident in the bureaucracy. Yet Hessen-Darmstadt struggled to reconcile some of the same contradictions that plagued Germany as a whole: it was geographically divided with Protestants in the north, and a blend of Protestants and Catholics in the south. Though Hessen-Darmstadt had promoted agricultural reforms advantageous to peasants as a member of the Rheinbund, it later joined Prussia's Zollverein which brought disaster to peasants.

In Prussia, the successful reforms of agronomist Albrecht Thaer (1752-1828) embraced yet other contradictions, combining chemical and economic approaches to agricultural reform with traditional practice and Romantic philosophy. It seems odd to encounter elements from the Enlightenment, Prussian conservatism, and German Romanticism in one historical movement, but reality is seldom packaged as neatly as our historical categories.

Thaer promoted the humus theory, stipulating that plants fed only on water and humus. It is a theory of death and rebirth: humus, the topmost organic layer of soil, is composed of the rotting remains of plants and animals. Thaer supported

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his humus theory with chemical analysis, arguing that the carbon, hydrogen, oxygen, and nitrogen of humus passed, as a complex compound, directly into the plant. In order to account for minerals, such as phosphates or silica, found in plant ashes, Thaer simply supposed that Lebenskraft enables plants to transmute elements. Thus the metaphysics of humus lent itself to Prussian conservatism: God, acting through Lebenskraft, set the organic realm apart from the inorganic one; the soul of the Prussian farmer therefore is one with the soil.

Other chemists, while not so single-minded or influential as Thaer, also made significant contributions to agricultural chemistry. Nicolas Théodore Saussure (1767-1845), in particular, anticipated Liebig's work in many ways. Nonetheless even Saussure never achieved a workable synthesis of agricultural chemistry and plant physiology; nor did he ever fully abandon the humus theory. Liebig's Metamorphosis: from organic chemistry to the chemistry of agriculture.

Liebig published his *Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie* in 1840. Immediately popular, it appeared in nine German editions, and nineteen editions in nine other languages. In part, its popularity lay with Liebig's superb manipulation of its initial release in Germany, France, and England. As a turning point in Liebig's life, it helped launch him into the arena of public life, an area beyond the internal concerns of science. Yet his motives for writing the book were internal to the history of chemistry.

There is little connection between Liebig's book and either his so-called doctoral dissertation or the 1837 request of the British Association for the Advancement of Science for him to write reports "on the state of isomeric bodies ... and on the state of organic chemistry and organic analysis."[11] Neither did Liebig write the *Anwendung* as solution to social problems.[12]

Liebig's was moved to write the *Anwendung* as an expression of certain metaphysical concerns and as the culmination of a decade of work in organic chemistry. His metaphysical interest was in a phenomenon he called metamorphosis. For Liebig, metamorphoses were processes of organic decomposition which occur when partially decomposed and unstable organic molecules, e.g. yeast, contact undecomposed plant or animal matter. The atoms of the plant or animal matter are set into motion, their compound's equilibrium, i.e. viz inertiae, is overcome, and it decomposes into two or more simpler compounds.[13]

Initially, Liebig proposed metamorphosis as a Cartesian chemical concept intended to counter catalysis, the Leibnizian phenomenon proposed by Berzelius. As a Cartesian concept, metamorphosis took into account only matter, motion, and contact. As a Leibnizian concept, catalysis involved dynamic forces emanating from sources outside the reaction itself. Catalysis was, therefore, incommensurable with metamorphosis. This difference marked the end of friendship between Berzelius and Liebig, the rising popularity of materialism,

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and the dominance of a new generation of chemists led by men such as Liebig and Jean-Baptiste Dumas (1800-84).

A series of metamorphoses constituted the Kreisläufe that were a central subject of the *Anwendung*, and of Liebig's subsequent work on animal physiology. Lebenskraft still lurked somewhere in the plant or animal organism, as Liebig occasionally acknowledged perhaps to avoid charges of Godless materialism, but the chemistry could all be explained without invoking mysterious spiritual forces. Thus, Liebig's *Anwendung* was a strong argument against the humus theory, and encouraged the development of inorganic mineral fertilizers to promote the growth of crops.

Liebig of course did not allow his scientific concerns to interfere with promoting the popularity of his new book. To this end, he developed a comprehensive plan that depended on close relationships with his German publisher Eduard Vieweg (1797-1867), his French translator and former student Charles Gerhardt (1816-56), and his English translator and student Lyon Playfair (1818-98). Meanwhile, he groomed his German audience by publishing a scathing polemic *Der Zustand der Chemie in Preussen*. *Zustand* was neither tactful nor factful: according to Liebig, there was not a single chemical laboratory in Prussia! Further, he made a strawman out of Naturphilosophie, as the cause of the rotten state of chemistry in Prussia and of widespread belief in the humus theory. *Zustand* did seem to achieve Liebig's purpose, by stirring up controversy and drawing much attention to his name before the publication of the *Anwendung*.

The Object of Organic Chemistry

Liebig began the *Anwendung* with a statement of his mission:

> The object of organic chemistry is to discover the chemical conditions which are essential to the life and development of animals and vegetables, and, generally, to investigate all those processes of organic nature which are due to the operation of chemical laws.[14]

This mission was carried out, in the first edition, in three ways: (1) He wrote in a familiar persona and utilized an inductive style of argument. Both contrast with previous publications on agricultural chemistry; (2) In overturning the humus theory, he set forth three positive programs that could be tested and developed further using experiment and observation; (3) For those concerned with the metaphysics of his work, he provided the theory of chemical metamorphosis.

Overturning the humus theory involved both internal standards of scientific evidence, and external "politics of science." Plant physiologists typically were

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deeply suspicious of conclusions drawn from chemical studies. They clung to common sense correlations between manure input and plant growth. Because of this, Liebig's campaign necessarily take the form of a humus theory vs. mineral theory debate.

Liebig's arguments against the humus theory included: 1) the chemical properties of humus as an inert and relatively insoluble compound; 2) a material balance based on the low solubility of humus and woodlands where timber and firewood are routinely taken away without replacement; 3) the lack of a humus-source for the original plants (Urpflanzen). If plants obtain carbon from the air, in the form of carbon dioxide, then the humus theory is simply not necessary. Liebig took no credit for the originality of this argument, and took care to credit his many sources of information, such as Saussure.

In pressing further a non-vitalist, i.e. materialist, understanding of plant physiology, Liebig likened photosynthesis to common inorganic chemical reactions, such as the generation of hydrogen when an aqueous solution of carbon dioxide acts upon zinc, and the reaction of chlorine and hydrogen gases exposed to sunlight. The overall Kreislauf of carbon, then, could be explained without recourse to vitalism. Liebig developed a parallel Kreislauf for nitrogen.

Liebig's investigation of the Kreisläufe for carbon and nitrogen, and his finding that these elements were seemingly unlimited, led him to emphasize soil minerals as limiting factors in plant growth. His mineral theory was inductively derived from plant ash analyses and numerous observations, such as the connection between soil phosphorous and the yield of grain crops. In order to augment soil minerals, or to replace those taken to market as grain, meat, and milk, Liebig developed an original system of solutions.

In proposing these solutions, he drew on his chemical philosophy and long experience with chemical manufacturing. For Liebig, a chemical was merely a chemical. A plant would utilize phosphate from a mine as readily as phosphate from a cow barn; no aura of Lebenskraft clung to the molecules of phosphate in cow manure. Thus a host of plant nutrients were potentially available as "artificial manure," and Liebig helped complete the modern industrialization of agriculture which had begun with processes such as beet sugar refining.

The Early Reception of Liebig's Agricultural Chemistry

When Liebig first became interested in agricultural chemistry in 1840 as a means of working out the metamorphoses of organic compounds in plants, he was, in contrast to some of his contemporaries, a chemist with no dirt beneath his fingernails. In his early involvement with agricultural chemistry, he sought to "elucidate the chemical processes engaged in the nutrition of vegetables,"[15] and he expressly avoided both field experiments and an overly pragmatic

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orientation. As Liebig explained to Lyon Playfair, his loyal student and translator, "You know I do not intend to write agricultural chemistry, but rather a chemistry of agriculture. I must avoid everything with regard to the practice of agriculture."[16] After publication of *Anwendung*, he turned his attention to animal physiology, and hoped to quit the chemistry of agriculture.

Shortly after 1840, however, a number of factors combined to chain Liebig's attention to agricultural chemistry. These factors also ended his purely theoretical and speculative orientation to it. Liebig's commercial inclinations, encouragement from former students, controversies with his contemporaries, and the socio- political events of 1846-48: all pushed him, by 1850, into a deep commitment to the practical consequences of his chemical principles. In this section, I shall explain the reception of Liebig's *Anwendung* primarily through the eyes of others, and reserve Liebig's response for the following section.

Lyon Playfair was one of the first to check Liebig's principles using field tests. In so doing, he also utilized an industrially produced fertilizer. Playfair's enthusiasm, and the popular reception of Liebig's *Anwendung* among the British agricultural community, helped renew and sustain Liebig's interest in agricultural chemistry.

Not all of Liebig's enthusiasts studied with him at Giessen. Alexander Petzholdt (1810-89) published a book on geology, which impressed Liebig and was a model for his own *Anwendung*. The two began a correspondence, and Petzholdt sung praises of Liebig's work. Petzholdt encouraged Liebig to begin writing his famous series of "chemical letters" as a means of popularizing scientific ideas. Petzholdt also published a simple and practical book of his own which was based on Liebig's *Anwendung*.

As might be expected, Berzelius was among the early critics of Liebig's non-vitalist theory of plant nutrition. He simply could not agree with the reduction of organic chemistry and especially physiology to simple explanations based on the same principles as inorganic chemistry: for Berzelius, there had to be an extra "something," i.e. Lebenskraft. By 1840, Berzelius was an old man with little new to contribute to chemistry. His student, the Dutchman Gerardus Johannes Mulder (1802-80) picked up the glove.

Mulder wrote a two volume, 1300 page, text on chemical physiology. He adopted some of Liebig's views, but adamantly opposed Liebig's reductivist and materialist approach. According to Mulder, organic elements such as carbon possess dormant Lebenskraft from their association with living organisms. When again taken up by plants, this "slumbering powers" (schlummernden Kräften) is awakened, and new, non-chemical powers once again emerge.[17] Humus, in effect, made topsoil semi-alive. Mulder realized the wider, political implications of his views vs. Liebig's. To Liebig, he wrote: "One sees that humus acid has a very conservative role in the soil; therefore, it does not appeal to many in these political times."[18] Perhaps because of the

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political nature of his times, Mulder's work never achieved the popularity of Liebig's.

Liebig's friend and publisher, Vieweg, told Liebig he must answer the criticism of Mulder, Sprengel, and others. Liebig did this in the pages of his journal and, eventually, in a revision of *Anwendung* (1843). Liebig's thinking changed on various aspects of the chemistry of agriculture, and sometimes provided his critics with the weak spot they sought. For example, by 1843 Liebig believed more strongly than ever that no ammonia need be supplied to plants from the soil.

The popularity of Liebig's books helped promote research on the chemistry of agriculture. Though often wrong, Liebig asked the right questions, and led agronomists to frame chemical answers. The Frenchman Jean Baptist Boussingault (1802-87) was the intellectual leader of the agronomists who criticized Liebig's ammonia theory. Much of Boussingault's work was based on field trials, and it soundly established the role of soil ammonia as fertilizer. Similar criticism ensued from British agronomists such as James F. W. Johnston (1798-1855) and other members of the Royal Agricultural Society. In the German states, similar field trials by Julius Stöckhardt (1809-86) were piling up evidence against Liebig's rather simple and theoretical views. By about 1850, increased scientific sophistication and thorough field testing on the part of the agronomists simply proved more successful than Liebig's program.[19]

The Decline of Liebig's influence on Agronomy

Initially, Liebig showed no interest in profiting from his ideas. He presented himself to fellow scientists and to others, such as Prime Minister Peel of Britain, as a scientist merely interested in doing his part for improving agriculture and society. Liebig soon had a change of heart, however, and decided to become, or return to being, a man of commerce as well as a man of science. Like Liebig's earlier decision to become a professor, his turn to commerce in 1845 might have been influenced by social aspirations: in early 1845, he was ennobled. As a member of the aristocracy, he needed land, and land cost money.

Liebig designed a series of mineral manures for various crops, and engaged his friend James Muspratt to manufacture them for the British market. The elder Muspratt, in turn, charged his two sons with the task. Since Liebig did not wholly trust these two, he employed two former students as his agents. Laboratory and field testing of the new Patentdünger was minimal.

Liebig was in a rush to market the Patentdünger because he needed money, his theories needed proof, and British farmers were in trouble. The grain harvest

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of 1844 had been very poor, and 1845 marked the onset of the potato famine. Farmers were grasping at straws, and Liebig was hurrying to sell them some.

The Patentdünger failed. There were supply and manufacturing problems, and it was too insoluble to make significant amounts of needed minerals available to plants. The quick failure of the Patentdünger in England was in one sense fortunate, for it helped prevent a similar embarrassment in Germany, where Liebig also intended to manufacture and market it. Word of the failure spread throughout Europe, and helped undermine Liebig's credibility with agronomists.

After the fiasco with Patentdünger, Liebig backed away from the chemistry of agriculture and busied himself with the chemistry of animal physiology and with writing popular science. When he again took up the chemistry of agriculture in the mid-1850s, agronomists again took up their old criticism of Liebig, i.e. that his theories were constructed in the laboratory and at the writing desk, and not tested through practice. To counter such criticism, Liebig published a small book in 1855, in which he claimed to have performed field trials from 1845 to 1849. Though historians have long accepted Liebig at his word, he probably never performed field trials.

Liebig did arrange to buy a property near Giessen, since called die Liebighöhe, in late 1844, a few months before word of his ennoblement became official. His books were selling well, his theories were generally well received, and he expected great profits from his investment in chinoidin (a pseudo-quinine). The new Baron described his plans for the new estate in several letters; field experiments were not part of these plans: instead, Liebig wished to construct an English garden and a charming summer house. Following the collapse of the "chinoidin caper," Liebig's funds were exhausted, and he decided to sell the land to his gardener in late 1847. Thus was Liebig's claim of having performed agricultural experiments on Liebighöhe from 1845 to 1849 an exaggeration at best. I believe Liebig had already contracted for the manufacture of Patentdünger in Germany when news of its failure came from England in April 1846. Liebig then disposed of the artificial dung which had already been produced in Germany, knowing it was practically worthless, by spreading it over his land, and instructing his gardener to plant crops there. Throughout, Liebig seems to have kept no records of these alleged field trials.

The revolutions of 1848 impressed Liebig deeply. Much of the political unrest resulted from hunger. The notorious Irish potato famine coincided with two years (1846-47) of wet cold weather on the continent. Both grain and potatoes were in short supply. In Baden, where the political turmoil was especially strong, and the hunger especially sharp, Liebig's name became famous in 1848, for his ideas offered some hope. Following the revolution, the university in Heidelberg offered Liebig a lucrative position. Though he refused it, it impressed an important lesson on him: hunger caused social unrest and political

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problems, and he had a solution for hunger. A new era began for Liebig, and he was quick to spread the word in his popular *Letters on Chemistry*:

> Without an acquaintance with chemistry, the statesman must remain a stranger to the true vital interests of the state, to the means of its organic development and improvement; .... The highest economic or material interests of a country, the increased and more profitable production of food for man and animals, ..., are most closely linked with the advancement and diffusion of the natural sciences, especially chemistry.[20] When the state is shaken to its foundations by internal or external events, when commerce, industry, and all trades shall be at a stand, and perhaps on the brink of ruin; when the property and fortune of all are shaken or changed, and the inhabitants of towns look forward with dread and apprehension to the future, then the agriculturist holds in his hand the key to the money chest of the rich, and the savings-box of the poor; for political events have not the slightest influence on the natural law, which forces man to take into his system, daily, a certain number of ounces of carbon and nitrogen.[21]

Conclusion

With Liebig's new appeal to political and social unrest as reasons for encouraging science, he found a new audience. His chemical work had already earned him deserved fame, and his influence on the development of agricultural chemistry had further widened his audience. Liebig now became a member of the aristocracy of science. He was tired of the work of teaching and researching and in 1852, at the age of 49, felt like an old man. When King Maximilian II offered Liebig a post with the Bavarian Academy of Science, he accepted it.

From this position, and without teaching duties, Liebig researched animal physiology and greatly influenced the development of this new field. Officially, he also promoted Bavarian industry and agriculture, but never with great success. In part this was due to the death of Maximilian II in 1864, and his inept successor, the mad King Ludwig II. The great vindication of Liebig's philosophy of chemistry as a central science for promoting economic and industrial growth came in Baden, through the success of several of Liebig's students.[22]

For Liebig, it had been a long way from Darmstadt to Munich. He proved adept at both the internal and external workings of science, and as the 19th century grew up, Liebig grew with it. In his lifetime, he never achieved the grand syntheses he had predicted, such as the manufacture of sugar from basic compounds like water and carbon dioxide.

His students and other chemists working in his tradition did achieve great things, as proven by our dependence on pharmaceuticals and artificial fertilizer. Perhaps the application of Liebig's programs has proven too successful, for we have depleted mineral and energy reserves at an alarming rate, and created more garbage and pollution in this century than in the entire earlier history of

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humankind. Perhaps the new Liebigs will teach us how to use our garbage and pollution as raw materials for a new program of synthesis.

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2 Quotation from Isabel V. Hull, "Feminist and Gender History Through the Looking Glass: German Historiography in Postmodern Times", Central European History 22/3-4 (1989), 279-300.

3 See L. Pearce Williams, Michael Faraday; A Biography (London 1965); Isabel V. Hull, The Entourage of Kaiser Wilhelm II (Cambridge/New York 1982); Margaret W. Rossiter, The Emergence of Agricultural Science: Justus Liebig and the Americans, 1840-1880 (New Haven 1975).

4 From my dissertation, Chapter One was published as "Social Climbing through Chemistry: Justus Liebig's Rise from the niederer Mittelstand to the Bildungsbürgertum" Ambix 37 (1990), 1-9; Chapter Four as "Liebig's Metamorphosis: from organic chemistry to plant physiology" Ambix 38 (1991), 135-154; and a revised portion of Chapter Two as "The Liebig Research School: historographic artifact and anachronism", to be published in a volume edited by Brigitte Hoppe, based on papers for an international workshop "History of Inter-relations between Biology, Chemistry, and Physics in the 19th Centuries", held at Ladenburg, Germany, 11-16 Sept. 1991.

5 Andreas Kleinert, Ed., "Hochwohlgeborner Freyherr:" Die Briefe an Georg von Cotta und die anonymen Beiträge zur Augsburger Allgemeinen Zeitung (Mannheim 1979).

6 William Hodson Brock, Ed., Justus von Liebig und August Wilhelm Hofmann in ihren Briefen (1841-1873) (Weinheim 1984).

7 Jacob Volhard, Justus von Liebig, 2 vols (Leipzig 1909).

8 Kenneth L. Caneva, Robert Mayer and the Conservation of Energy (Princeton 1993). For Caneva's eloquent and thoughtful perspective on the historiography of Liebig and his contemporaries, see his review of Lenoir's The Strategy of Life (Boston/Dordrecht 1982): "Teleology with Regrets", Annals of Science 47 (1990), 291-300.

9 Note that, in my interpretation, Liebig's early interest in the connection between plant and mineral chemistry is a myth stemming from apologists like Volhard.

10 Thomas Pynchon, Gravity's Rainbow (New York 1973), pp. 411-413.

11 In addition to the details in "Sturm und Dung", see W.H. Brock and Susanne Stark, "Liebig, Gregory, and the British Association, 1837-1842", Ambix 37 (1990), 134-147.

12 This false and misguided account has been promoted by the sociologists of science, Wolfgang Krohn and W. Schäfer.

13 Later, Liebig and his followers enlarged the concept of metamorphosis to include the synthesis of higher compounds from simpler substances.

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14 Justus Liebig, Organic Chemistry in its Applications to Agriculture and Physiology, trans. Lyon Playfair (London 1840): 1. I have cited the English translation since he translated under the direct supervision of Liebig, and I have found it to be accurate.

15 Liebig, Application (1840).

16 Liebig to Playfair, 14.8.41. Imperial College Archives.

17 See Mulder, Versuch einer allgemeinen physiologischen Chemie, trans. H. Kolbe (Braunschweig 1844).

18 Quoted from Schling-Brodersen, Entwicklung und Institutionalisierung der Agrikulturchemie im 19. Jahrhundert: Liebig und die landwirtschaftlichen Versuchsstationen (Diss. TU Braunschweig 1989), p. 66.

19 For the details of Liebig vs. the agronomists, see Mark Finlay, "Science, practice, and politics: German agricultural experiment stations in the nineteenth century". PhD dissertation, Iowa State University, 1992.

20 Liebig, Familiar Letters on Chemistry, trans. Gregory (London 1851).

21 Ibid, p. 483.

22 See Peter Borscheid, Naturwissenschaft, Staat, und Industrie in Baden (1848-1914) (Stuttgart 1976).

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