

Chemical Glasgow and its Entrepreneurs, 1760-1860

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The principal focus of this essay, the town of Glasgow and the chemical works of St. Rollox, is local, but has a general resonance, for St. Rollox may be regarded as a paradigmatic case of industrialized chemical production within the encompassing orbit of the industrial revolution. Here, inarguably it seems, are found the kinds of research-based, knowledge-induced technical innovation, entrepreneurship, growth rates, scale transformations, employment and wage patterns, which allow assimilation to the historiographical normativity of industrialization, at least in British terms. The most recent and conceptually sophisticated treatment of St. Rollox informed by the history of chemistry is found in Hasok Chang and Catherine Jackson's edited volume on *The Life of Chlorine*.¹ The authors critique the technologically determinist, linear approaches of older writers on the history of chemical technique, which explained the history of chemical and industrial development in chlorine bleaching through a narrative structured by progressive innovation moving from science to technological advance to industrial production. In its stead they recommend an approach emphasizing the complex, contingent and feedback looping elements characteristic of interpretation based upon 'social shaping of technology'.

The approach adopted in this essay has some kinship with this advocacy, but has additional characteristics. Its most acute focus is upon 'situation', the town of Glasgow, and the industrial site of the St. Rollox chemical works within it.² It equally emphasizes contemporary Glaswegian sites of chemical produc-

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- 1 Manichi Chung, Saber Farooqi, Jacob Soper and Olympia Brown, "Obstacles in the Establishment of Chlorine Bleaching," Hasok Chang and Catherine Jackson, eds., *An Element of Controversy: The life of chlorine in science, medicine, technology and war* (London: British Society for the History of Science, 2007), 153-178, for chlorine bleaching in this period, and for St. Rollox in particular 168-74; First published nearly fifty years ago, Alfred Musson and Eric Robinson, *Science and Technology in the Industrial Revolution* (Manchester: Manchester University Press, 1969), 231-371, remains the most informatively detailed treatment of British chemical technology and manufacture during the period.
 - 2 There exist few archival sources for St. Rollox and no substantial history of the company. The Mitchell Library Glasgow holds site-development plans 1830-1900, and legal depositions. I have located an early letter-book, useful primarily for business organization, and have additionally

tion other than St. Rollox, and the infrastructural development of educational and collective commercial institutions within the town. It further focuses upon the chemical-entrepreneurial figures, Charles Tennant and Charles Macintosh, at the center of St Rollox chemistry and industrial expansion. As young men, they worked in a pre-industrial manufacturing setting. Their careers therefore allow us to track practical chemistry's transition from pre-industrial to thoroughly industrialized settings, a period coinciding with the rapid sequence of development in chemical science during this period. Because some narratives of industrial revolution emphasize qualitative, ultimately discontinuous change, these two careers thus also provide an opportunity for critical attention to that historiographical reflex, with respect both to practical chemistry, and to industrialization. Further, as 'entrepreneurs of the Industrial Revolution', Tennant and Macintosh, in their very different ways, repay analysis of the varied forms of chemical-entrepreneurial activity they exhibited. This affords critical reflection upon the vocabulary of technical and economic 'innovation', and more particularly, upon models of entrepreneurship which currently preoccupy economic historians. Are chemical entrepreneurs easily absorbed by such models as further exemplars, or might they induce attention to a more nuanced understanding of entrepreneurship?³

A Chemical Behemoth

The St. Rollox Chemical Works, owned and operated by Charles Tennant and Co. in Glasgow, was often described as being, in its mid-Victorian heyday, the largest in Europe, if not the world. Across numerous measures (physical extension, employment, product diversification and output, fuel consumption, cost reduction) the company exhibited exceptionally impressive growth. Growth and size are however often matters of relative judgment, and parameter-dependent. The economic historian may wish to fix upon financial elements, such as annual financial turnover, rates of profitability and the like, as opposed to physical extension of site and other physical detail. There is a point to such

used contemporary accounts, family histories and biographies, and informal local and parish histories.

- 3 For recent work on entrepreneurship in this period, see François Crouzet, *The First Industrialists: The problem of origins* (Cambridge: Cambridge University Press, 1985); 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.

selectivity. Site-wise a large bleachfield might compare in acreage with early St. Rollox, indeed there was one such in Glasgow, but its financial parameters would have nonetheless stood in stark contrast. One might alternatively think of employment size, for a large site does not of necessity employ large numbers (think again of the bleachfield). There is also interesting international comparison to be made on the question of size. The Gunpowder Manufactory run by the British military in Ichapur, India, employed more than two thousand workers, at least triple the number of St. Rollox workers in the 1820s, and at a considerably earlier date, and this example serves also remind us that, during the eighteenth century, and into the nineteenth, the employer with the highest number of workers engaged in manufacturing, on the largest sites, was the government, in particular the Army and Navy offices, with their extensive dockyards and munitions works.⁴

St. Rollox originated as a chlorine bleaching manufacture in 1797, sited in a semi-rural location, north of Glasgow, close to the newly completed Monkland Canal. Tennant used a Berthollet chlorine bleaching liquor, then modified with the addition of lime (as opposed to potash). The move to the Tennant-Macintosh patented chlorine bleaching powder in 1799 was the key element in St. Rollox' early expansion, the powder remaining an ongoing profitable staple of production throughout our period. The site diversified internally, producing sulfuric acid and soap, and after the abolition of salt importation duty in the early 1820s, Leblanc process soda, both ash and a lesser amount of crystal. Its physical plant grew, and was improved, with expensive installation of platina vats (instead of lead) for concentrated vitriol, more furnaces, chimneys, warehouse storage, canal basin, and railway terminal in 1831. By the 1850s the company had its own on-site cooorage, a foundry for equipment-making, and interests in local coal mines. The central chemical works alone had come to occupy thirteen acres. Tennant also began purchasing sea-going schooners, the basis by 1848 of a large mercantile fleet on the river Clyde, with steam vessels for the London and Baltic trades, and coastal sailing vessels for limestone importation (Ireland) and sulfur (Italy).⁵ St. Rollox site-expansion was spectacular, but, through Tennant's relentless application, it became in local, national and international terms also geographically tentacular, by rail, and by water – thus Leviathan accompanied Behemoth.

4 Jan Lucassen, "Working at the Ichapur Gunpowder Factory in the 1790s," *Indian Historical Review* 39 (2012): 19-56 (part 1), 251-71 (part 2); With thanks to Andreas Weber, who brought this work to my attention.

5 James Dawson Burn, *Commercial Enterprise and Social Progress: Or, gleanings in London, Sheffield, Glasgow and Dublin* (London: Piper, Stephenson & Spence, 1858), 118.

Contemporary perceptions of St. Rollox recorded its massive productive presence in the north of Glasgow. J.D. Burn was struck by its 'stupendous' size overall, the enormous bulk of the vitriol vats and the chlorination chambers, the mountainous tonnage of heaped chemical raw materials, the hundreds of furnaces, the heat, and the staggering amounts of materials consumed and produced. St. Rollox's impact upon visitors, dutifully noted in quantitatively numerical terms, was equally registered in physical, material terms other than simple tonnages consumed and produced. To Burn's awed perception, and in his laudatory account of a progressive manufacture, there was nonetheless consciousness of an infernal working environment, an 'extraordinary labyrinth', a 'devil's den', dominated by the 'monstrous' dimensions of an immense chimney, 'Tennant's Stalk'.⁶ Its material penetration of the surrounding environment became as noticeable. George Dodd's description a decade earlier was comparable with Burn's, noting St. Rollox gigantism, monstrosity, and the bewildered impressions of the novice observer, but unlike Burn, it also emphasized the deleterious working environment, both hazardous and unhealthy.⁷

This progressive narrative had already received cultural registration in educated, popular bourgeois and upper-class reading, whereas one needs to look to demotic and musical working class expression for registration of dissent from the progressive narrative, and contrasting emphasis upon working conditions. Tennant and Co. appeared in Walter Scott's *The Antiquary* as an item of common conversation in a provincial east-coast town, its thriving business noted, and its commercial prospects speculated upon, a readily intelligible sketching of common communicative life, and to that extent a witness to the company's rising and pervasive presence in Scottish commercial culture.⁸ A contrasting view of St Rollox is found in verses recited by Hugh Aitken Dow at a Royston School reunion in 1875, a school founded by Tennant's for the children of their workers, so the likelihood is that Dow was a local resident, and had been a St.

6 Ibid., pp. 114-119.

7 George Dodd, Charles Knight, James Thorne, Harriet Martineau, William Harvey and William Wylie, *The Land We Live In: A pictorial, historical and literary sketch-book of the British Islands*, vol. III, Scotland, Ireland and the Devonshire Coast (London: William Orr and Co., 1846), 213.

8 Walter Scott, *The Antiquary*, original publication 1816, edition referenced is *The Antiquary*, vol.1 (New York: Van Winkle and Wiley, 1816), ch.15, 154, 160; *The Antiquary's* representation may be somewhat anachronistic. The novel is set in the 1790s, at which time Tennant's had existed at most for four years. It is possible that the company's extended network of business agents and volume of sales at that time was such as Scott depicted, but it is at least as likely that it represents the state of affairs around Scott's time of writing, 1815-16.

Rollox chemical worker, perhaps as early as the 1840s.⁹ Invaluable as a direct comment by a chemical worker, Dow's verses portray the oppressive, sooty and sulfurous atmosphere of the St. Rollox Works and its surroundings, and also its physiological effects, 'smarting eyes', and 'muffled noses'. A nether-world is again invoked, with a concluding image of Vulcan, but, the verses insist, the god of fire, forge and metallurgy can no longer compete effectively with St Rollox. Later in the century, the nose of St. Rollox' chief chemist, nicknamed Sniffer Crystal, had been eroded, by his constant olfactory occupation of gauging chemicals.¹⁰ If St. Rollox was comparable with contemporary English chemical works, then indoor workers, in the vitriol rooms, the soda sheds, or at the chlorination chambers, would after a number of years be moved to work outside in the yards, so deleterious were the effects of working the chemical processes.¹¹ Chemical workers were of course acutely aware of such specific occupational consequences, and of occupational life expectancy.¹²

It is difficult to avoid the conclusion that St. Rollox' general environmental and particular physiological impacts were pervasive, oppressive and unhealthy. The chimneys poured smoke, soot and chemical fumes into the sky, a subject of sarcastic pictorial comment. In terms of an Aristotelian material cosmos, St. Rollox' coverage was absolute. Earth and water absorbed its chemical waste. The air was increasingly contaminated by its carbon and gaseous exhalation, the fire of the furnaces flamed incessantly, and the ethereal sky was occluded by the smoke, rising to join Glasgow's often low cloud ceiling, whose frequent rain returned fractions of the furnace carbon and acidic fumes to earth.

None of this is of course particularly surprising. We are narratologically accustomed to accounts of economically progressive, massive and continuous output expansion, technological innovation, factory labor concentration and exploitation, with the downside consequences of urban pollution, disease and crowded, squalid housing, and we are comparably accustomed to an accompanying, progressive 'science and technology' narrative, old-fashioned

9 Text available at the Royston Road Project, <<http://www.roystonroadproject.org>>, section "Garngad & Royston"; For music, listen to Ron Angel or Big Big Sea, "The Chemical Worker's Song", both available on YouTube. This is a twentieth century song, also known as "The Process Worker's Song", sometimes "The 101 Song", and features life expectancy, caustic burn, gypsum and cyanide.

10 Simon Blow, *Broken Blood: The rise and fall of the Tennant family* (London: Faber and Faber, 1987), 59.

11 W.A. Campbell, "The Alkali Industry," Colin A. Russell ed., *Chemistry, Society and Environment* (Cambridge: The Royal Society of Chemistry, 2000), 75-106, on 82.

12 Anon., "Glasgow Sketches," (1889), a compilation of nineteenth century excerpts from local newspapers, Mitchell Library (Glasgow Room), ref. G330.193.01444 MIL.

perhaps, but still exerting influence, and which may be briefly sketched as follows. In Sweden, the chemist Scheele observed chlorine's bleaching properties, with experimentation on plant materials. In France, Claude-Louis Berthollet undertook further experimentation, producing the innovative technique of chlorine-based liquor bleaching, which he publicized to French bleachers. James Watt learned of his new process, which, although difficult and dangerous to manage, possessed potential advantages over existing bleaching techniques, particularly the reducing of cloth bleaching to direct chlorine treatment, eliminating the lengthy techniques of alternative alkalization and acidification followed by time-and-space consuming exposure to sunlight. It could all be moved indoors, and done with the newly discovered, liquefied chlorine gas, with cost reduction and labor-process reconfiguration possessed of developmental potential. Berthollet was close to the heart of the chemical revolution in France, and its new chemistry of gases. This scientific context had thus produced dramatically innovative technique, publicized through Berthollet's benevolent, philosophical commitment to human betterment, and James Watt informed colleagues and compatriots of it when he returned to Britain. Amongst them were the progenitors of St. Rollox. Tennant and Macintosh adopted the liquor technique with some modification, and commenced the new works with it. Within a few years, they effected a radical improvement in the new chemical technology with a process which produced a powder, and this produced significant further cost savings, particularly in relation to packaging, transport and distribution, the liquor being much heavier, bulkier, and prone to lose its efficacy, than the powder. The technical revolution originating in and accompanying the chemical revolution was now essentially complete, and the result in Scotland was St. Rollox and its economically expansive and culturally iconic, if ambivalent history, forged by the practical chemical acuity and exceptional entrepreneurial abilities of the Tennant and Co. partnership. Such a 'linear' account, neatly enough, conjoins a history of pure science terminology of experimentation and discovery and applied science-driven technological innovation, with the equally significant terminology of innovative industrial entrepreneurship – a tale of two revolutions, discontinuously instituting modern chemistry and modern urban industry, whose integration proved to be an unstoppably powerful and transformative historical force, whatever evaluative attitudes historians may hold towards it. Without denying the factual basis for the progressivist narratives of chemistry and industry, it is nonetheless possible to use further historical detail in ways which refuse simple endorsement of them, and introduce further resources for conceptualizing and narrating the origins and development of key aspects of chemical manufacture and industry, practical chemical technique, chemical science

and education, chemical entrepreneurship, and Glasgow itself, within the period 1760-1860.

Behemoth Deconstructed

We have long known of the very considerable difficulties, of chemical technique, experimental and practical development, of competition and cost and hazard to health, which attended attempts to introduce Berthollet's oxymuriatic liquor into commercial production in the late 1780s and 1790s. The extensive and detailed research of Musson and Robinson revealed a lengthy series of efforts, in Lancashire, Nottinghamshire and the west of Scotland, to introduce chlorine bleaching on a commercially viable scale.¹³ From Berthollet's original work until the patent application for the Tennant's powder took fourteen years. Those years were filled with further practical chemistry experimentation, numerous trials involving a variety of different technical apparatus (containment vessels for acid and gas, complicated flask arrangements for managing the gas, a measurement device for gauging bleaching strengths), direct gas-to-cloth treatment, and a number of different chemical additives to liquors to manage both the degree of caustic strength and the respiratory and ocular hazards of working with chlorine.

Processes which worked with linen did not necessarily work with cotton. Printed calicos offered further problems. Alkaline addition diluted bleaching efficacy, and transport of bulky, heavy liquor was not propitious. Some became convinced that even with workable and reliable liquor, the whole process would be just too costly for commercial viability. The competitive environment induced levels of secrecy, and of betrayal, among the groups trialling the varieties of new processes. The new processes themselves, if successful, would, it was feared, face further competition from combinations of old-method bleachers, who would co-operate to undercut new-method prices, a particular vulnerability given the anxious cost estimates of new-method trialists. Several competing groups of manufacturing chemists devoted sizeable investment of time and money, convinced of the chlorine route to a radically reformed commercial bleaching. At least three of these groups, each containing experienced bleachers and reputable practical chemists, nonetheless ended in failure, and were obliged to give up on this particular chemical quest. Then when some reliably usable liquors were formulated, and the Tennant's powder emerged as

13 Musson and Robinson, *Science and Technology*, pp. 251-337 (see note 1).

a further reliable option, this by no means signaled the effacement of the older techniques.

The process of ‘innovation’ was not simply ‘difficult’ and ‘bumpy’; this really does not capture the reality of the case. It was long-drawn-out, populated with serious financial hazard and a substantial business failure rate; at any given moment within the period, it appeared as entirely contingent upon a large number of chemical, technical and business variables; and as an historical process it continued to remain incomplete, as the persistence of older methods in tandem with new tended to demonstrate. Any account of the chlorine innovation which focuses simply on Berthollet’s discovery at one end and successful powder manufacture at the other is thus prone to ignore the actual historical process of what gets called, and singularized, as ‘innovation’. The process was multiple in its attempted novelties, and most of them failed over the medium term.

Further investigation, details of which now follow, tends to indicate the misleading insufficiency of solely ‘revolutionary’ narratives, insofar as their underlying concept of change is one confined to radical innovation inducing discontinuous development. It also indicates the inadequacy of accounts of chemical Glasgow’s patterns of development focused solely on the pre-eminent case of St. Rollox, and questions the limiting nature of entrepreneurial modelling derived from the paradigm industries of the period, cotton, steam, coal, mechanics and the like.

Chemical Glasgow

The analysis which follows is geographical in the first instance, based as it is on an informative Glasgow map of 1828.¹⁴ Its particular virtue is clear identification of Glasgow’s sites of manufacture with precise location, and calculable area occupied by works sites. It is firstly possible to form an accurate impression of the range and number of manufacturing concerns. Cotton Works (twenty-two) and Foundries (eighteen) predominate numerically, and there are only two strictly denominated ‘Chemical Works’. To form a more accurate impression of chemical manufacture, we should however add to these the other producers of chemicals, the four Soda Works, two Gas Works, and the

14 David Smith, *Plan of the City of Glasgow and its Environs* (Glasgow: Wardlaw & Co., 1828); For zoom facility, legibility and close inspection navigation, see University of Glasgow Library’s site: <<http://www.gla.ac.uk/services/library/collections/virtualdisplays/mapsofglasgowhistoricaltodigital/davidsmith1828planofthecityofglasgowanditsenvirons/>>

Acid and Vinegar Works; and also the eight Dye Works, the two Crystal (leaded glass) Works and the Coal Tar Works, making a total of twenty-one manufactures where chemical products, crucial chemical processes, manipulation and practical chemical expertise were fundamentally involved.¹⁵

This total still excludes the highly chemical potteries, the refineries, breweries and distilleries, but for chemical completism with reference to Glasgow, note two further sites, those of the University of Glasgow and the Andersonian Institution, where chemical science was taught. In this overall picture of chemical Glasgow, the sheer size of St. Rollox, (the dark section at the top of the north-west quadrant of map section, Fig. 13.1) still predominates as notably the largest manufacturing site in the city; but we should note too that the largest sites tend to be chemical, exemplified in addition to St. Rollox by the main gasworks (south-west quadrant), and the Cudbear Works (south-east quadrant). The latter two will also prove to be of particular significance in the developmental pathways we will shortly follow. For the time being, the considerable presence of both cotton and iron manufactures, each of them probably outnumbering chemical manufactures in employment terms, may be noted, along with the extensive areas occupied by chemical production.

The textile sector and the chemical cannot of course be functionally separated in local or national terms, in that the expansion of bleaching and dyeing materials which is registered on David Smith's map is directly ascribable to coeval expansion of cotton textile production, witnessed by the number of Glasgow cotton works. The contrast between Glasgow textiles and chemicals at this time is between the large number of smaller units of production in cotton, and the smaller number of large units of production in chemicals. The proliferation of four soda works in addition to St. Rollox is explicable in terms of the recent abolition of salt importation duty, reminding us of the crucial role played by government policy in directing the course of industrial development.

To this picture of the comparative placement of chemical manufacture within Glasgow's industrial setting we can add further relevant detail from academic, educational chemistry. Anderson's Institute numbered in its trustees and professors men with chemical interests. Macintosh was a trustee, as was his business associate John Wilson, whilst Willian Couper, another friend and business associate, became a teacher of chemistry there.¹⁶ The University of

¹⁵ Figures compiled from Smith, *Plan of Glasgow* (see note 14).

¹⁶ Roger Emerson and Paul Wood, "Science and Enlightenment in Glasgow, 1690-1802," Charles Withers and Paul Wood, eds., *Science and Medicine in the Scottish Enlightenment* (East Linton: Tuckwell Press, 2002), 79-143, on 97-99.



FIGURE 13.1 Section of David Smith, Plan of the City of Glasgow and its Environs, 1828. Showing (1) St. Rollox Chemical Works, Charles Tennant & Co. (2) Glasgow Gas Works, George and Charles Macintosh. USED WITH THE KIND PERMISSION OF UNIVERSITY OF GLASGOW LIBRARY.

Glasgow by this time possessed a distinguished genealogy of teachers of chemistry, including William Cullen, who worked on both salt and bleaching process manufacture in the 1750s, Joseph Black who worked on bleaching agents and pursued artificial soda with James Watt, and William Irvine, with his particularly relevant and meticulously quantified analysis of the properties of sulfur in heating and cooling.¹⁷ By the time of this survey of the late 1820s, the University's professor of chemistry was Thomas Thomson, an early supporter of Daltonian atomism, with interests also in pursuing the gains made by German analytical chemistry, and making these gains tell with regard to chemical teaching and research.¹⁸ The work of these academic chemists had a variety of bearings upon the practical chemistry of manufacturers, in particular the early attention (1750s-1770s) to alkalization in bleaching and the potential of lime, and Thomson's enthusiasm for Hermann Klaproth's ruthless analytics, which left no residue unexamined.

Some of William Irvine's pupils and associates formed a small Chemical Society whilst in Glasgow, in 1785-7. Whatever the chemical preoccupations of the Glasgow students, the society helped cement relations between two young men who would continue their association momentously, as original, founding partners of Tennant and Co., namely Charles Macintosh and the above-mentioned William Couper.¹⁹ This noteworthy group also contained two more sometime professors of chemistry, Adair Crawford of the Woolwich Military Academy, and John McLean, professor at the College of New Jersey; also Alexander Tilloch, publisher of *The Philosophical Magazine*, John Finlay, a close chemical correspondent of Macintosh, and John Wilson of Hurler, where he and Macintosh would initiate Scotland's first alum works. Macintosh contributed papers on dyeing, crystallization and alcohol, this last exhibiting familiarity with Lavoisian chemistry.²⁰

The Chemical Society thus offered opportunity for young chemists to pursue their particular, practical chemical interests, but at least as important for the future of manufacturing chemistry were the emergent associative bonds which it fostered. From this associational point of view, two further institutional venues have relevance. The Glasgow Chamber of Commerce, the first of

17 William Irvine, *Essays, Chiefly on Chemical Subjects* (London: J. Mawman, 1805), 475-90.

18 For Thomson, see J.B. Morrell, "Thomas Thomson: Professor of chemistry and university reformer," *British Journal for the History of Science* 4 (1969): 245-286; and idem. "The Chemist Breeders: The research schools of Liebig and Thomas Thomson," *Ambix* 9 (1972): 1-46.

19 Emerson and Wood, "Science and Enlightenment," pp. 128-129 (see note 16) fn.63 has detail on this society; An earlier useful source is George Macintosh, *Biographical Memoir of the Late Charles Macintosh* (Glasgow: Blackie & Co., 1847), 6-8.

20 *Ibid.*, pp. 6-8.

its kind in Britain, was started in 1783, immediately in the wake of the peace ending the American War of Independence. The 1780s marked something of a shift of commercial focus, away from colonial trade monopolization of tobacco and toward domestic manufacture. This shift is noticeable in the Chamber of Commerce's early focus upon improving the quality of manufactures, and influencing government on tax and tariff. Charles Macintosh became a member, and his father, George, was an early president of the institution. Thus, when Macintosh joined the founding partnership of St. Rollox, it meant that Tennant, who tends to be regarded as senior partner (he took over financial control early on), was forging a relationship with the pre-eminent chemical manufacturers of Glasgow, the Macintosh family. One might begin to think therefore, that Tennant joined the Macintoshes, rather than the reverse; in the *Memoir* of his father, George jnr. mentions that Macintosh and Tennant were, "for several years previous", business partners by the time of *both* St. Rollox bleaching patents (that is, previous to 1797).²¹ The thought is reinforced by consideration of the fact that two of Charles Macintosh's business associates in the Hurllet alum works, John Wilson and James Knox, were also partners in Tennant and Co. The Hurllet alum works was virtually contemporary in origin with St. Rollox, and in associational business terms, the firms had overlapping partnerships. This circumstance, and its timing, serves to emphasize the way in which, by the second half of the 1790s, this forceful grouping of chemically-inflected manufacturers had attained the chemical and commercial confidence to undertake not a single but a double initiative with reference to the foundation of major new enterprises.

In the 1780s and 1790s then, Glasgow clearly exhibited a set of educational and collective commercial institutions, voluntarist in nature other than the University. From our viewpoint, these institutions did not simply teach and promote chemical science and its manufacturing uses and potentials. They also generated and sustained a chemico-commercial culture, visible nodes of association for commercially-oriented chemists whose ties of friendship, family and manufacturing business would provide social cohesion to the development of Glasgow's chemical manufactures in the coming decades.

Chemical Entrepreneurship. The Staple Highway: Charles Tennant

The narrative of St. Rollox' origin, foundation, spectacular growth and commercial success, whilst acknowledging the significance of Charles Macintosh,

21 Macintosh, *Biographical Memoir*, p. 37 (see note 19).

tends to be understandably dominated, in terms of human agency, by the figure of Charles Tennant, a compelling story of transformation of a young rural silk weaver into the industrial Colossus of St. Rollox, an epic socio-economic trajectory of the industrial revolution. Young Tennant was a silk weaver, working in this highly-skilled occupation in Ayrshire. Aware perhaps of the increasing demand for textile bleaching, from long-established linen and recently growing cotton textile production, he switched occupation to bleaching, and ran a rural bleachfield in Darnley, Ayrshire, from 1788. There, hearing of Berthollet's chlorine technique, most likely *via* James Watt or Watt's father-in-law the bleacher John McGrigor, both of whom were working on improvements to the Berthollet technique, Tennant commenced, after some experimentation, using the Berthollet potash-chlorine liquor with success, eventually modifying it by substituting lime for the potash. His neighbour at Darnley was William Wilson, whose daughter Tennant would later marry in 1795. Wilson, a merchant and factor to the Earl of Glasgow, also had a son, name of John, whom we have already met, a fellow member of the University Chemical Society with Charles Macintosh, and a business associate of Macintosh in the nearby Hurlet Alum Works, sited on land owned by the Earl. Three years later, shortly after the foundation of Tennant and Co., the firm took out a patent for the chlorine liquor (eventually lost in an informative court case of 1802), but further experimentation, using slaked lime and chlorine gas, produced the solid bleaching powder which replaced the liquor, and provided the chemical basis of St. Rollox' early ascent, and some financial basis for its expansion. The local communicative networks of family, friends, Chemical Society and business association were clearly instrumental in forming the genesis of St. Rollox and its new bleaching chemistry.

Thus far we have Tennant as the alert, opportunistic, young entrepreneur, moving occupation riskily from a skilled to a less skilled occupation with more expansive potential, pursuing new processes, recognizing talented expertise and incorporating it by business association into ambitious commercial novelty. This does not, however, suffice as a characterization of the way he developed St. Rollox, which, after the new bleaching powder, may be considered as chemically conservative. That is, it concentrated on long existent methods, not chemical innovation, for producing basic staples, such as soap and sulfuric acid, rather than new methods for new products. When Leblanc process soda was adopted in the 1820s, it was certainly new in Glaswegian and Scottish terms, but it was by no means the first artificial soda, and all the pre-installation start-up costs, experimental research, up-scaling, equipment design, were absent, for by then it was a known and tried process of chemical production, with a waiting market, relatively riskless. Similarly, the lead

chamber process for sulfuric acid had been practiced in Scotland since 1749, at John Roebuck's Prestonpans manufacture. Tennant's concentration was not on radically innovative technique, other than the bleaching powder, but on using St. Rollox for radically increasing the quantities of common, basic chemical materials and products. The language of 'growth', 'expansion' and 'innovation' tends to obscure this conservative, and fundamental, feature of St. Rollox chemical production.

Other notable features of Tennant's entrepreneurial practice include the distributed network of sales agents, and his concentration on packaging, transport and product distribution. One reason the Glasgow-Garnkirk railway was an early arrival in Scottish rail development terms was Tennant's early realization of railway's advantages. He befriended George Stephenson, and worked to ensure the Caledonian Railway spur to Garnkirk. The mercantile fleet also displayed his attention to transport, now in national and international import-export terms. In all these forms of development, Tennant's entrepreneurial style exhibited the impulse to own and control as many facets of the commerce as possible. In addition to production of relatively riskless chemical staples, the on-site packaging, immediate rail and water access, and the sea-going fleet bespoke a quest for, and ability to achieve, not simply maximal control and the co-ordination advantages derived therefrom, but as much independence as possible, relative freedom from reliance upon other packagers, distributors, and raw material suppliers.

Externally to the company, Tennant also paid effective attention to politics, acting for the advance of St. Rollox with the Leblanc process by pushing for abolition of salt importation duty, and opposing one chemical vested interest, which wished to prevent the advent of artificial soda. This interest was the Kelpers, numerous on the Scottish islands and west coast, the gatherers and burners of seaweed, or at least the proprietors and managers of estates where such work occurred. They produced much of the potash used in Britain, a strategically significant group in terms of chemical manufacture. This was the underlying conflict. It was about whether or not artificial soda, which needed mineral salt, would chemically supplant the established, vegetable-derived potash, rather than simply about free trade and Treasury receipts on salt, and Tennant and St. Rollox emerged a winner in the conflict.²²

22 Obituary of Charles Tennant, Institution of Civil Engineers Letter Books, 9 vols. 1839-49, vol. 1, Shelf Mark 624/629 (410)31G.

Secret Works and Serial Invention: Charles Macintosh

If Tennant's entrepreneurship after bleaching powder can be described as chemically conservative, staple-focused quantitative expansion, complemented by strategic political action where necessary, and by in-house development and control of as many commercial factors as possible, then consideration of Charles Macintosh's complex and varied career, marked by serial manufacturing initiatives, multiple business associations and chemical invention, offers a striking contrast in entrepreneurial character. The relevant background pre-dates his birth in 1766, for the Macintosh family were already chemical manufacturers. His father George, with the financial aid provided by the Glasgow tobacco trader John Glassford, took over an established and patented, though then failing, dye making business in the 1770s, starting manufacture at Dunchatton in east Glasgow (see Fig. 13.1 for location of cudbear dye works). Macintosh Snr., "who is a great hunter after secrets", employed the previous owners of the process as managers.²³ The dye, named cudbear, was lichen-derived, and chemically capable of manipulation of color gradations through pink and red to blue and purple, and the Macintosh manufacture proved successful and long-lived. At its inception and for decades after it possessed two very striking features. It was surrounded by high walls, to hide the production processes from the curious eyes of 'intelligencers' or spies. In this its protective design followed that of Roebuck's lead vat acid process at Prestonpans. Even more striking was the work force, composed of Highlanders who were largely monoglot Gaelic speakers. The Macintosh family came from the northern county of Ross-shire, and they knew that Scots Highlanders were already familiar with the process, at least in undeveloped terms, because they used lichen to make their own textile dyes. The work force was essentially internally imported, semi-skilled labor, and the workers numerous. They were moreover sworn to secrecy, attended a nightly roll call, and were housed on-site, inside the walls. Many rarely left the compound, nor learned any English.²⁴ George Macintosh had erected a quadruple security barrier, of oath, roll call, wall and language, to protect the details and practice of the cudbear process, and the security would seem to have worked insofar as no other cudbear

23 McGrigor to Watt, April, 1788, cited in Musson and Robinson, *Science and Technology*, p. 293 (see note 1).

24 George Stewart, *Curiosities of Glasgow Citizenship; As exhibited chiefly in the business career of its old commercial aristocracy* (Glasgow: Maclehose, 1881), 70.

manufacture appeared in Glasgow.²⁵ Dunchatton was thus a remarkable socio-historical enclave, a site of production whose fuller comprehension requires appreciation of internal migration from the *Gaidhealtachd*.²⁶ Industrial urbanization of such populations, and the persistence of local Gaelic cultures in such circumstances are also important.²⁷ This place, of chemical enclosure and jealously guarded secrecy, was where Charles lived from childhood, the Macintosh house being on site and also functioning as the company office.

Charles at a still youthful age, as well as attending the chemistry class at Glasgow University (and Joseph Black's in Edinburgh, also later Thomson's in Glasgow), participated in the family business, traveling on at least two occasions, to Germany, Holland and France, on sales business for the company, and for the Prestonpans acid works, now taken over by John Glassford. He probably also pursued chemical intelligence, experimenting on French plants for dye potential, and noting Holland's sugar of lead manufacture and its successful export business to Britain.²⁸ He started his own entrepreneurial career before he was twenty, a sal ammoniac plant comparable to James Hutton's in Edinburgh. This commenced an entrepreneurial career of a large number of chemical manufacture initiatives, by no means all successful, but some of which brought him further prosperity, scientific reputation (F.R.S 1823), and eponymous commercial renown (the 'Mackintosh' [*sic*], a waterproof coat). He commenced sugar of lead manufacture in 1786, apparently lowering costs enough to export to Rotterdam, successfully undercutting prices of the Dutch sugar of lead manufacture which had so impressed him on his continental tour. He and his father learned of efforts in trials of the new chemical bleaching, and in 1788 Charles was "making experiments at home in order to find out the secret", then traveling to Manchester to learn more.²⁹ He had also launched mineral acetate production, substituting lime for alumina, a British novelty, and of use particularly in calico printing. He would start the Hurlet Alum works with John Wilson, and initiated a further alum site north east of Glasgow

25 Though see *ibid.*, p. 71, where he records that one Highlander absconded to London, providing technical information to a company which set up short-lived cudbear production.

26 The Gaelic speaking areas of Scotland.

27 For informative analysis of such processes, see Charles Withers, *Urban Highlanders: Highland-lowland migration and urban Gaelic culture, 1700-1900* (East Linton: Tuckwell Press, 1998).

28 This and following detail on Macintosh's chemical career are taken from Macintosh, *Biographical Memoir*, particularly the "Introduction," pp. xii-xix, and the additionally narrated accounts of Macintosh's activities throughout the main text (see note 19).

29 Musson and Robinson, *Science and Technology*, pp. 293-4 (see note 1).

in the Campsie hills. The production of the chlorine bleaching powder for the new Tennant Co. in 1798, again highly novel in its gas-to-solid (chlorine-to-slaked lime) reaction, occasionally ascribed to Tennant, was the foundational experimental work of Macintosh.

The torrent of manufacturing processes did not cease with the establishment of St. Rollox, where he remained as a partner until 1814. For the East India Co. he produced a fused saltpeter process with considerable weight and space saving for stowage capacity for sea transport from India, the process demonstrated to the Directors' satisfaction, but not adopted. On the dyeing front, in addition to continuing the Cudbear Works, and the Turkey Red dyeworks started by his father in 1787 with the aid of Papillon's expertise in the "secret", he established a Prussian Blue process, and prussiate of potash for calico printing.³⁰ Prospecting at the Glasgow Gas Works he found naphtha (a coal tar derivative), a by-product of the coal-gas production. Either detecting its India rubber-dissolving property himself, or more likely knowing of James Syme's discovery of it in Edinburgh in 1818, he formulated the production of water-proofed cotton by using sheets of rubberized naphtha sandwiched between layers of cotton, an eventually successful manufacture which he relocated to Manchester. His last significant cooperative venture was with James Nielson, an eventually successful patenting, in 1828, for Nielson's hot-blast furnace metal-smelting process. His initial acquaintance with Nielson was probably a result of his prospecting of the coal tar by-products at the Glasgow Gas Works, where Nielson was a foreman. Prior to that, he had produced a new preparation of iodine, further innovations in textile treatment for calico printing, started a yeast factory in London (eventually failing), and patented an iron-steel conversion process with carburetted hydrogen.

Overall, his activity differed substantially from that of Charles Tennant. Less single-minded and more diversified than Tennant, his operations nonetheless possessed an identifiable internal coherence, for instance in the number of projects focused upon textile treatment and dyeing. The alum works and acetate process were relevant from this viewpoint, the potential application among others being their specific properties as mordants. He also used Glasgow Gas Works ammonia by-product in the Cudbear processes. We tend perhaps to over-individuate in our focus on sites, and this can misdescribe their functionality. Instead of individualized accounts of Macintosh's apparently diverse manufactures, an account which recognizes a chain of enterprises, succes-

30 Macintosh, *Biographical Memoir*, p. 22 (see note 19); George Macintosh Snr., writing to Charles, claimed to have thoroughly improved upon what they had from Papillon, improving color and shortening dyeing time.

sively connecting alum, ammonia and acetate with cudbear, Turkey Red and thence outward to calico printing, is more realistic for appreciating the overall coherence of these aspects of Macintosh's entrepreneurship.

Further characteristics reinforce the contrast with Tennant. Macintosh was far more mobile, a well-traveled and well-educated practical chemist, not solely Glasgow-sited, and willing to divest himself of existing enterprises (the Turkey Red Works and St. Rollox) to free his capacity for further initiative in chemical production. His multiple projects tended to remain of medium size, unlike the singular gigantism of St. Rollox, and a thread of persistent chemical novelty, chlorine powder, mineral acetates, dyes and mordants for calico printing, rubberized cotton, ran through them. Stated thus, the Macintosh successive chemical coverage of the key chemical processes prior to actual textile treatment by bleach and dye becomes readily apparent.

Just as indicative of his entrepreneurial character was his already indicated habit of chemical prospecting and scavenging. His first effort, sal ammoniac manufacture, relied, like Hutton's, on the free waste product of soot. The alum works were firstly based on cast off schist from local coal mines. The naphtha was an unused gas production by-product, like the ammonia. The point of scavenging in this sense is not just the finding of new materials. The materials were available, unintentionally as it were, and in the first instance, as the result of the labor of others. First-phase production thus came if not for free, at least for reduced cost. Nowadays we might understandably call him a chemical recycler, or re-purposer, but perhaps that does not quite capture the prospecting and scavenging habit quite spectacularly displayed by Macintosh. Rather, he gave chemical purpose and commercial value to the purposeless and valueless cast-offs of others' labor.³¹ Mobile, prospective, scavenging, qualitatively diversifying rather than quantitatively accreting, this increasingly expert and chemically innovative entrepreneurial practice thus provides a thorough and instructive contrast with Tennant's and St. Rollox.

These chemical entrepreneurs were indubitably successful in chemicoeconomic terms, but the routes to success, the staple chemical highway of St. Rollox, the longer, twisting trail of multiple chemical and manufacturing initiatives followed by Macintosh, show that in this period, no singular entrepreneurial mode was definitive of chemical manufacturing success. Nor are these entrepreneurs straightforwardly assimilated by current modelling of industrial revolution owner-industrialists and of entrepreneurship, although a degree of comparative light is thrown upon them by recent work.³² They may,

31 See Simon Werrett's and Lissa Roberts and Joppe van Driel's essays in this volume.

32 Crouzet, *The First Industrialists*, and Mokyr, "Entrepreneurship," (see note 3).

for instance, be described as broadly middling rank in origin (Tennant specifically a skilled, independent artisan), and both had extensive prior experience in the manufactures they industrialized. However, unlike some other significant industrial-scale works owners, Tennant did not undertake sector diversification that we know of into forms of finance, nor into non-chemicals within the manufacturing sector, nor enterprise outside manufacturing other than his in-house mercantile shipping.³³ Judgment of Macintosh's entrepreneurial characteristics should not allow his diverse set of medium scale operations to obscure the sense of coherent functional interaction of the textile-directed chain of the various operations, nor ignore his prospecting and scavenging proclivities, modes of entrepreneurship not easily recognizable in available models. As partner-owner of one large-scale enterprise, and with reference particularly to his range of inventive abilities, technical expertise and scientific cultivation, he is comparable especially with fellow-Scot James Watt, perhaps also with James Keir in the Midlands, and Thomas Henry in Manchester. The work of Peter Jones has rendered this a type more categorically recognisable than hitherto, the distinctive '*Savant-Fabricant*' figures of early industrialization, men who successfully combined scientific knowledge, technical expertise and manufacturing experience.³⁴

Joel Mokyr's essay on entrepreneurs in the industrial revolution continues his strategic interpretive stress upon institutional and cultural factors.³⁵ He picks out the behavioral normativity of gentlemanly politeness and trust, the latter particularly significant with respect to contract and credit; trade associations and informational networks; and the strategic importance of choice of partners in new industrial ventures. This latter point is dramatically endorsed by the St. Rollox partnership of Tennant and Macintosh. With respect to local Glasgow commercial culture, we might add two sorts of relevant institution not covered by Mokyr, the new formal and quickly chartered collective institution, the Chamber of Commerce, with its focus on manufacture; and, of genetic significance, the University, not simply for its chemical teaching, nor yet for any commitment to techno-scientific public communication, but for the voluntarist association of the Chemical Society, and the combination of chemical enthusiasms, personal and commercial associations at whose origins it lay. Overall then, we may at least start to think of Glaswegian chemical entrepreneurship as partially intelligible within some recent analytical perspectives of

33 For such diversification see Crouzet, *First Industrialists*, pp. 16-17 (see note 3).

34 Peter Jones, *Industrial Enlightenment: Science, technology and culture, in Birmingham and the West Midlands, 1760-1820* (Manchester: Manchester University Press, 2009), 116-29.

35 Mokyr, "Entrepreneurship," (see note 3).

economic history, but at the same time, as having additional and different features to extend and qualify such historical understandings.

Conclusion

By way of conclusion, it may be worth reflecting on the broader issue of the nature of the historical developments involved, as premised in discontinuous conceptions of chemical and industrial revolutionary change, and as gesturally represented above (in the section “Chemical Behemoth”). Certainly the expanding St. Rollox site represented a visibly dramatic step-change, both for chemical manufacture generally, and for bleaching powder, then acid and soda production specifically. Also certainly, the chemical knowledge of Macintosh was up-to-date, informed by the new chemistry of Lavoisier and his French colleagues, and the new chemical technique of St. Rollox is directly relatable to a key component of revolutionary chemistry, namely the multiplication of gas discovery, the properties and compositional implications thence investigated, and the provocation all this provided for a systematic reformulation of the science, together with its practical methods of analytical and synthetic procedure. Macintosh’s chemical circle was clearly aware of this. One friend wrote, in 1786, four years before the English translation of Lavoisier’s *Traité élémentaire*, “From the perusal of Fourcroy’s chemistry, I have become a perfect convert to the aerial system, although I think most of the disputes on this subject, and the doctrine of phlogiston, are mere playing on words.”³⁶ This evidenced the chemical attitudes of the young practical chemists, keenly interested in the very latest chemistry, their focus particularly on the systemic role of gas components, the ‘aerial system’, but not overly distracted by intractable theoretical dispute. To this not inconsiderable extent, the changes in question, chemical, technical and economically productive, do not require violent shoe-horning into a narrative stressing intensive, discontinuous change.

There are however other detailed features of change which further complicate any straightforwardly discontinuous emphasis. Remaining for the moment with the chemical dimension of manufacture, the key role of chlorine needs a fundamentally qualifying addition. The first Tennant & Co. patent, for bleaching liquor was lost in 1802, because it also specified lime in suspension, which Tennant had used to replace Berthollet’s potash additive, and lime was already in comparable bleaching use, a point sufficient in the legal specifications of

36 John Finlay to Charles Macintosh, February 1786, in Macintosh, *Biographical Memoir*, p. 19 (see note 19).

the time to invalidate the patent. The second St. Rollox patent was for the dry bleaching powder process, chlorine-based but crucially dependent on the reaction with slaked lime to produce not liquor but powder, the great commercial advantage of St. Rollox. Whence and why the lime?

Since 1750, bleaching had chemically modernized with sulfuric acid, produced by Roebuck's works, and considerably shortening bleaching time. In the 1760s Edinburgh's academic chemists Joseph Black and Francis Home had argued chemically for the introduction of legally banned lime, convinced of its relevant property, under appropriately focused quantitative management.³⁷ Tennant and Macintosh were also lime enthusiasts in this genealogy of Scottish bleaching technique, Macintosh in particular likely to have known of the work of Black and Home. From this viewpoint, first Tennant, then Macintosh, might be considered not as adding lime to chlorine, but adding French chlorine to chemically established Scottish lime. If that may be thought of as tendentially overstating the case, then consider also Macintosh's statement to a correspondent: "Lime has long been a favourite nostrum of mine, having first used it many years ago."³⁸ He used it with reference to sal ammoniac, alum and elsewhere, and had thorough familiarity with its properties in its mild, caustic, liquid and slaked states. It was his familiar chemical standby, a first port of reactive chemical call. It was thus utterly unsurprising that he should investigate its potentials in chlorine combinations. Lime, so to speak, does the business, in its itinerary through sal ammoniac, acetate, alum and chlorine processes of production. In this sense, Macintosh was not simply a 'modern' chemist, but an educated and knowledgeable inheritor of the previous generation of pre-revolutionary chemists' practical and theoretical knowledge. Chemically, therefore, we require an equal stress upon pre-revolutionary chemistry to understand the genealogy of St. Rollox bleaching. That in turn induces an authentically continuous dimension to the chemical history of St. Rollox.

Distinctive features of the Cudbear Works also bear more extended examination for their presence elsewhere. Its early modern, pre-industrial retentive secrecy, reminiscent of Prestonpans, was not Macintosh's only secretive process. The Campsie alum works was also known as the 'secret works', as, in imitation of cudbear manufacture in Glasgow, Macintosh attempted to sequester details of his alum process. The Turkey Red Works and 'secret' were also

37 Joseph Black, "An Explanation of the Effect of Lime upon Alkaline Salts," Francis Home, *Experiments on Bleaching* (Dublin: T. Ewing, 1771), 265-282.

38 Macintosh to his Tennant business partner, James Knox, Glasgow, 20th January, 1800, in Macintosh, *Biographical Memoir*, p. 25 (see note 19).

sequestered. This surviving ethos of pre-industrial manufacture can be contrasted with Tennant's far more communicative attitude, for example his willingness to instruct Irish bleachers. Macintosh worked for a time with Lancashire bleachers, but retained an attitude of guarded secrecy toward aspects of development of the Berthollet process, as indeed did James Watt, both men unwilling to forego any competitive edge which withheld chemical knowledge might provide.³⁹

The partners' practices, both convergent and divergent at particular moments, illustrate the ways in which pre-industrial behavioral reflexes could and did persist, contemporary with the supposed liberal openness of a knowledge-based industrial economy, or more precisely, the way in which a publicly communicative ethos of accessible exchange of scientific and technical knowledge had a differential uptake with respect to manufacturing practice, even as between close entrepreneurial partners.⁴⁰ These kinds of concluding examples, emphasizing the persistence of various kinds of pre-revolutionary commercial forms and behaviors, and of chemical knowledge and practice, coeval nonetheless with consciousness of fundamental change in chemical science and with comparably fundamental economic development, reinforce the need for a more nuanced historiographical semantics, capable of registering and relating all relevant forms of change during the industrial and chemical revolutions.

39 For the introduction of Berthollet's process in Britain and the role of James Watt, see Musson and Robinson, *Science and Technology*, pp. 251-337 (see note 1).

40 The thesis of the growth of an openly communicative techno-scientific culture in this period is argued in Joel Mokyr, *The Enlightened Economy: An economic history of Britain, 1700-1850* (New Haven and London: Yale University Press, 2009).