# Material matters – but how?

**Nicky Gregson: Department of Geography, University of Sheffield**

## 1: Introduction

Taking materiality seriously, or – in another form – re-materialising enquiry, is increasingly a clarion call in certain areas of the social sciences, including human geography, anthropology and parts of sociology. Like many such calls, however, this one is strong on assertion, and rather less convincing when one starts – and here I use a deliberate metaphorical tactic – to scratch the surface of such claims. Indeed, one of the paradoxes of several recent attempts to engage with materiality in the social sciences is precisely their rapid retreat from the physical register to the altogether more familiar terrain of representational worlds, of meaning and communication; a shift that some have labelled as a slippage from the material to the immaterial (Miller, 2005). Certainly, we can see this in the pioneering work in the STS tradition, and in some of its close intellectual kin, notably ANT, as well as in material culture studies, in which a starting point frequently located in particular objects (or even materials) is rapidly overlain with, and taken over by, symbolic registers.

My starting point in this paper, however, is that this programme requires us to engage seriously with a materiality that is, if not 'out there', certainly physical, even if that physicality is not entirely separate from our understandings of it. In an earlier paper, and building on previous work (Hudson, 2001, 2005), Hudson (2008) stakes out one way in which this might be done, conceptualising CPE (or should it actually be economies?) in terms of three discrete but interacting registers – political economic, semiotic and material – constituted, in turn, through circuits and (non linear) flows, and worked out in relation to particular sites and spaces. Material here is construed at the most abstract of levels, as biological, chemical and physical transformations, and as flows of matter and materials. An important corollary of this position is the way it forces us to re-conceptualise the position of waste/s, not as the end point of value's loss but as a 'product of every stage in […] every material transformation' and therefore as 'integral to every stage in economic production'. However, there are tensions in this account that I want to explore, not least in terms of how a conceptualisation that is open to the complexities of an emergent economy and to the interplay between registers, sits with an account of material transformations that ultimately retreats to a re-instatement of linear stages in the production process. As I show here, this has more than a little to do with how we conceptualise and indeed think through materials transformations within economies.

If I am to summarise my difficulties with Hudson's argument here, they are around conceptualising materials transformations exclusively through the laws of thermodynamics and thinking of materials within economies – using Frosch (1997) – as '*a sequence of steps* (my emphasis) each of which "is more or less a transient event, a temporary (possibly long-lived but temporary) use of some set of atoms and energy". Hudson states: "each industrial process and economic activity *necessarily* (emphasis in original) involves the transformation of materials and energy from one form to another […] Thermodynamics provides very specific rules and limits that govern these transformations; they cannot be altered or suspended by human intervention […] The laws of thermodynamics state that energy is neither created nor destroyed during these transformations although it may change in physical form […] and that the total mass of inputs to a transformation process is equal to the total mass of outputs". This is fine, but only so far as it goes as a statement about thermodynamics, since it remains within the realms of C19th understandings. Indeed, what it overlooks is what Gribbin (2003, p 388) declares as 'arguably the most important and fundamental idea in the whole history of science', the second law of thermodynamics, which – in its second (entropy) form – states that the amount of disorder in the universe is always increasing and that, whilst order can be preserved, this is only ever local and achieved only through flows of energy from the outside (ultimately, the sun). Where this takes us ultimately is to the equivalence, and inter-changeability, of energy and matter (i.e. Einstein's 1905 statement $E = mc^2$). However, whilst such insights were of fundamental importance to the development of C20th physics, and science more generally, a key question is whether sub atomic and astronomical scales are an appropriate way of thinking through the sorts of material transformations that characterise many economic activities.

At one level, when we think about the relationship between economic activity, $CO_2$ emissions and climate change, they undoubtedly are. And clearly, the development of sustainable economic activities at the global scale requires a degree of engagement with such fundamentals. But, much of what concerns political economy – the registers in which it currently moves - works at very different scales, and with very different objects. Moreover, I remain unconvinced that thinking even in terms of C19th understandings of thermodynamics has that much to offer here. Do we really need to think in terms of energy and matter to work material transformations into an understanding of textiles and the textile industry, for example? Isn't what interests us about textiles less to do with energy and material exchanges and efficiencies, and rather more about the development of markets for new (including reconstituted) materials; how particular properties are manufactured into certain cloths and fabrics, through the use of synthesised materials (cotton and polyester for example), dyes and textures, which are themselves fabricated further into particular garments configured and fashioned for wearing in particular ways in different parts of the world? Or, to take a very different instance, but another from our programme, whilst an understanding of thermodynamics certainly forces an appreciation of the very real material limits that surround steel production, in the sense of the limits to achieving further efficiencies within a blast furnace, it is debateable what such appreciation brings, beyond recognition of its consequences, i.e. that steel produced from a blast furnace fuelled by coking coal is working at the limits of thermodynamic efficiencies, which means that the level of $CO_2$ emissions cannot be improved upon, which in turn has consequences for the steel industry in any move to develop a carbon-neutral economy. Such issues are still in the 'what-if' zone, whilst political economy has yet to engage seriously with the full implications of thinking through carbon. More immediately, however, does our understanding of the production of either highly specialised steel alloys or 'bog standard con-cast' benefit from thinking of these materials purely in terms of flows of matter and energy, rather than as very specific sorts of materials with very particular sorts of properties and capacities, which in turn are key to understanding their positioning within certain markets? I'm not convinced that it does. So, if I am to summarise my position. Yes, I agree, we *can* think economies through flows of matter and energy, atoms and molecules, but isn't the point more that the types of material transformations that are primarily going on within economies, as well as the ones that we are primarily interested in, are much more contingent. They are about *particular* configurations of atoms and molecules, their coming into being through their manufacture, and attempts to hold them (or not) in these configurations (as well as the unintended consequences of all this)? So, whilst I do not dispute in any sense the limits on transformations the laws of thermodynamics impose, or even the possibility of thinking in such terms about economies, such is their level of abstraction and indeed generality that they add little to an understanding of economic activity, it seems to me, other than by making the general limits points and by highlighting the inevitability of disorder. Indeed, one of the corollaries of such a position is that it risks being seen as highly mechanistic, even atomistic, in its conceptualisation of materials.

My second difficulty is with the way in which thinking in this way about materials transformation leads, seemingly inexorably, back to the kind of linearity that we are at pains to try to side-step, if not avoid, in this programme. Although vastly more attenuated, as well as less hide-bound to a connection with the final commodity than thinking through the commodity chain, thinking economies as 'sequences of steps' that are steps in the social (and economic) lives of atoms and molecules is, I would argue, but a very short way from the same thing, since to think in terms of sequences of practices and procedures with certain materials implies a particular temporal (and spatial) arrangement of activities, in the sense that transformation B *follows* transformation A, and is almost certainly *conditioned by the outcomes and properties of* A. Applied to classic economic objects of enquiry, this takes us back exactly to a linear conceptualisation of the production process, in which what 'goes in' in material terms at one end (iron ore, coking coal, limestone for instance) comes out at the other, in sequence (as steel) from a rolling mill, albeit that we might be rather more attuned to some of the things that are coming out as well along the way. Whilst this might be what is going on within a single plant, economies, even at the level of plant complexes, are not just about linear sequences such as this but also about a whole slew of simultaneous material transformations in time and space; material transformations then are always going on. Indeed, much of the difficulty for capital here is to co-ordinate these transformative activities spatially and temporally – to bring certain things together, at the right time, in the right place, in the right conditions, to a particular degree of quality. Moreover, what we know, from several industrial sociology style studies is that the coordination of material transformations doesn't always work. Machinery breaks down; employees (sometimes) 'put a spanner in the works'; materials fail quality control tests; problems with suppliers means that the supply chain fails to work 'just in time'; or - something even more profound intervenes to affect production – a Bhopal style event; BSE; bird flu. Production then, is rarely the smooth uninterrupted sequential flow of material that it is represented to be. And this has effects, not just on productivity but on materials, and what can be done with them (or not) by way of transformations. Steel that fails quality control is literally put back in the blast furnace; chicken meat that fails a quality control check in the UK would not just be 'wasted' (incinerated) but would likely result in a further raft of bio security measures for the plant (and supply chain) concerned (think Bernard Matthews). So, whilst our models of economies are that they are path dependent, the practice that is economies is about having to make paths connect, spatially and temporally, to continually bring them into being (and put them back together again) through the constant interplay of materials, people, procedures and activities. Intricate enough even at the level of a single plant, this is of positively mind boggling complexity when we think in terms of a globalising economy, but this is what it means, I think, to think in terms of complex, open and emergent economies.

In this paper I want to focus primarily on the first of these arguments – namely how best to think through working with atoms and molecules in conceptualising economies. This is not because this first is in any sense more important than my second argument, but it is – it seems to me – a prior step in the development of such a position. Indeed, in order to begin to understand economies in the ways I have sketched out requires that we have a thorough grasp of the processes of material transformation within particular industries. The question this begs, of course, is where does one begin in such an endeavour? Whilst the programme itself will provide various ‘cut-ins’, my point of departure here is rather different; with the chemical industry.

**2: Why chemistry?**

As Andrew Barry (2005) notes, to some chemistry appears a distinctly uninteresting discipline. Seen to embrace a naïve mechanism and atomism, represented as devoid of theoretical interest and as strictly a service science dedicated to techno-industrial utility, a more negative press for chemistry would be hard to imagine. Yet, as Barry goes on to argue, following Bensaude-Vincent & Stengers (1996), to see chemistry thus is to miss that chemistry’s theoretical significance lies not with any ‘larger theoretical claims or ethical implications but [… in its] attention to the singularity of the case’ (2005, p. 52). Built on experimental learning from the contingent, chemistry, Barry argues, is best thought of as ‘a new form of empiricism […] produc(ing) substances which cannot be derived from general laws (ibid, p. 53). Further, much of chemistry’s interest – for social science – lies in the translation of its learning, rather than straight application, between the laboratory and various fields of application, including factories, and the fields within which finished products are consumed, and – we might add – wasted (Gille, 2007). However, it is materials, their properties, and material transformations that have their antecedents in contingent experimental learning but which have undergone translation from the laboratory to the plant setting, that are the very business of the chemical industry. One consequence is that the practice of chemistry (academic and industrial) has itself been integral to developing understanding of materials, and matter. It is for this reason that it merits closer inspection here. Indeed, perhaps there is no better starting point in the quest to re-materialise our understanding of economies than with a subject that is simultaneously fundamentally alive to materials and oriented toward industrial utility?

As Bensaude-Vincent & Stengers show in their history of chemistry, chemistry’s development has been marked by very different understandings of materials, moving from the discovery of materials and their properties, to materials synthesis and – more recently – the invention of what they term ‘informed materials’.

> “Whether functional or structural, new materials are no longer intended to replace traditional materials. They are made to solve specific problems, and for this reason they embody a different notion of matter. Instead of imposing a shape on the mass of material, one develops an ‘informed material’, in the sense that the material structure becomes richer and richer in information. Accomplishing this requires a detailed comprehension of the microscopic structure of materials, because it is in playing with the molecular, atomic and even sub-atomic structures that one can invent materials adapted to industrial demands” (p. 206).

Whilst the development of informed materials is critical – economically as well as theoretically – it is nonetheless the case that such materials have not completely supplanted other understandings of and relationships to material. Alongside newer materials, the production of basic materials for industrial processes (the acids for example) still continues, as does that of key synthetic materials (rubber, plastics, dyes, drugs …). However, undeniably the new composite materials have had profound effects, not just on how we conceptualise materials, and their use, but on the organisation of production. Requiring close collaboration between various sectors, Bensaude-Vincent & Stengers note (p. 205) the new composites have led to a radical re-organisation of whole production sectors citing, as examples, the aerospace industry, as well as biotechnology, microelectronics and semiconductors.

Immediately, we see here the close affinity between conceptualisations of material and their materialisation, in the laboratory and in production complexes. Far from characterising just the nexus of new materials, this relationship between materials, their conceptualisation and their materialisation is – I suggest – an historical one, and simultaneously geographical. In what follows therefore, and to counterbalance the intense interest currently in new materials – an interest which, we might note, appears to be driven more by theoretical resonances than by their economic importance – I foreground the conceptualisation of materials that proved critical to the emergence of mass production in the C19th and C20th, that is the manufacture of substitute and/or replacement materials for traditional materials, or synthesis. My exemplar here is the Leblanc process, or manufacturing soda from sea salt. Regarded as the founder of industrial chemistry, the industrial counterpart as well as contemporary of chemistry's other 'founding father' the academic Lavoisier, Leblanc not only manufactured what was to become the first mass produced, industrial scale synthesis; he simultaneously produced a process that was itself materialised, in the form of specific plant, works and equipment, and whose materialisation had further effects. I begin however, not with Leblanc, but with Barry's point, that chemistry's theoretical significance lies not just in its conceptualisation of materials but in its attention to the singularity of the case. Rather than remain at the level of generality, then, I want to work with chemistry in ways that echo how chemists themselves work with material, through experimental learning from the contingent and its translation between fields. My initial vehicle here is Primo Levi's *The Periodic Table*, and specifically three stories which illuminate that material transformation, par excellence, is always a matter of contingency, experimental learning and translation.[1]

### 3: Primo Levi's *The Periodic Table*: of life and lives lived through material transformation

Narrated through elements, Levi's unclassifiable text is simultaneously particular and general; it is perhaps, for those who are not scientists, most readily interpreted as both a means to write autobiographically and to reflect on the human condition. Yet whilst Levi's writing life through elements performs metaphorically, its fascination for me is two-fold: in the way each of these 21 element stories simultaneously and continually insist that material always matters, whilst all the while narrating the life of the industrial chemist (as well as the life of a particular Italian Jewish chemist/writer, who is more well known for having lived through and written on Auschwitz – see Levi, *Is*

[1] A text with clear parallels is Oliver Sacks' *Uncle Tungsten* (2001).

*This a Man*).[2] This (working) life of the chemist emerges through the text as a life that is fundamentally about working in particular ways with particular materials – a life that is lived in proximity with and in conjunction with elements, molecules and their transformations within conditions that are simultaneously economic, chemical and technical. It is for these reasons that I think the text merits close investigation within this programme. In short, I think its stories give us a means to unlock how material matters in developing conceptualisations of economies (of practice). To open this up further, I want to focus on three of Levi's stories, which illuminate different ways of working with materials in the chemical industry and, in different ways, both my general argument about how material matters economically and how, particularly, we might conceptualise material transformation within the production process.

***Chromium – or a tale of revaluing material of zero net value***.

'He took me to a corner of the (paint) factory's yard, near a retaining wall: piled up at random, the lowest crushed by the highest, were thousands of square blocks of a bright orange colour. He told me to touch them: they were gelatinous and softish, they had the disagreeable consistency of slaughtered tripes. I told the director that, apart from the colour, they seemed to me to be livers and he praised me: that's just how it was described in the paint manuals! He explained that the phenomenon which had produced them was called just that in plain English, "livering"; under certain conditions certain paints turned from liquids into solids, with the consistency precisely of the liver or lungs, and must be thrown out. These parallelpiped shapes had been cans of paint: the paint had livered, the cans had been cut away, and the contents had been thrown on the garbage heap" (p 152).

Following Levi's encounter with the abject, he recounts being set the task of discovering, firstly, why the paint had turned from liquid to solid – and secondly, to reclaim the paint as paint. What follows is a tale that is forensic and chemical in equal measure; it entwines theoretical and experimental knowledge about what should be present in particular substances, and in what measures, with the learnt procedures of formal chemical analysis and the technical procedures and specifications of a production process intended to result in the generation of a particular material commodity. Indeed, Levi recounts working back from chemical analyses of the gelatinous blocks that disclose the presence of too much chromate, to the file cards that itemise the technical specifications and procedures that describe these materials. That the mutation from liquid to solid occurred is traced to an erasure on a file card, which resulted in 23, not 2 – 3, drops of a chromate reagent being added to the pigment. Task one solved, as an erasure materialised as a matter of excess, Levi sets about task two, eventually using ammonium chloride (which combines stably with lead oxide) to perform the reverse operation, turning solid to liquid, and livers to paint once more. There is, however, one final ironic twist to the tale: having solved the problem with the addition of ammonium chloride, the latter too enters the formula. With the pile of too basic chromates long returned to the state where they can realise

[2] Levi's life as an industrial chemist, working as an employee and then executive at an Italian paint company (SIVA), is documented by his biographer Thomson (2002, see Chapter 15 pp 257 - 9). Levi worked here from 1948 – 1977, whilst the company specialised in the production of paints, varnishes and lacquers as well as PVFs and PV adhesives, in which it became a major European player. The connections between this work and some of the stories in *The Periodic Table* are readily apparent. For a more academic consideration, see Gordon (2007)

value and having moved on from the factory, "*my ammonium chloride … by now completely useless and probably a bit harmful, is religiously ground into the chromate anti-rust paint on the shore of that lake and nobody knows why anymore*" (158 – 9).

There is a general point that I want to draw out from this story. This starts from the observation that this whole course of events unfolds only because of the presence in a certain paint factory of a material that has been cast on the rubbish pile. Not quite 'waste' in that it has not been thrown out, its material properties nonetheless render it utterly valueless on the market, in the sense that solid paint cannot be turned into money, or indeed use values. At the same time, the paint company cannot return the consignment because the paper work accompanying it decrees the pigment to have passed various inspection tests and to have been accepted on these terms. This 'paint', in short, discloses precisely those qualities that I have come to think about as an asset of zero value. Whilst we should note here the way in which paper works to codify material and to regulate its movement (even whilst all may not be what it is represented as being), a more important point for thinking economies through materials, is that in such circumstances the work of the industrial chemist (Levi) is to draw on and utilise knowledge (about materials, techniques, analysis, synthesis) to re-realise value, in this case through a material transformation that returns solid to liquid. More generally, what this suggests is that the realisation of value in this factory/industry is hinged to the temporal, physical and spatial stability of a particular material assemblage – a point made in this story by the addition of the ammonium chloride as well as by the primary narrative. Consequently, when such assemblages breakdown (for whatever reason), value is lost. This is not, of course, to say that physical stability is a necessary condition for value's realisation. Rather, it is the manufactured durée of material assemblages that matters. In Levi's paint factory that durée requires stability, that is, it is relatively stretched temporally; elsewhere it might not be so (think about convenience food for example), and indeed might be predicated upon the transience of particular material assemblages. In that durée however, is the life of value; whilst this durée may break up, when it does so the result is the social, cultural and economic death of material, value's loss. It is in such moments - when paint becomes slaughtered tripe, when processes generate assets of zero value – that we find material really mattering to economies.

***Nitrogen – or a tale of trying to make lipstick from chicken shit***

"*I devoted a day to coarse sifting of the chicken shit, and another two trying to oxidise the acid contained in it to alloxan … All I got were foul vapours, boredom, humiliation, and a black and murky liquid which immediately plugged up the filters and displayed no tendency to crystallise, as the text declared it should. The shit remained shit …*" (p181)

'Nitrogen' entwines alchemy with entrepreneurship and analysis with synthesis. As a story it begins as a tale of two lipsticks. One is French, and perfect; the other is Italian, and runs in wearing. The effect is less than impressive aesthetically, mutating from women's lips to faces, to "an ugly web of red threads that blurs the outline and ruins the whole effect" (p177). Levi's task, at least initially, is to use the techniques of chemical analysis to establish why one product is so superior and the other inadequate; in short, to use the tools of chemical analysis to uncover the material basis of contrasting aesthetic (and market) values. Through heating, he establishes that the lipstick that runs contains a soluble dye, whilst the other's dye is insoluble. Further analysis, by diluting with benzene and centrifugation, establish that this insoluble dye is an expensive pigment, alloxan. If the Italian cosmetic company is ever to compete with the French, it needs to start producing lipstick with alloxan, or its equivalent. Levi, consequently, is set the task of establishing whether he can get hold of this insoluble dye and/or a substitute. Consulting chemistry library schedules on molecular structure, the *Chemisches Zentralblatt* and *Beilstein* (an encyclopedia of synthesis), Levi establishes that a compound can be prepared through an oxidising demolition of uric acid, and that uric acid is to be found in high concentrations in the excreta of birds (50%) and reptiles (90%). He is confident that he will be able to deliver a sample of synthesised alloxan within a month – and the dream of a life of future riches seems within reach, spurred on by the allure of turning shit to gold, alchemy's legacy. What follows is hilarious accounts of attempting to collect chicken shit (in sufficient quantities) and Levi's resort to a snake exhibition in Turin. There he learns that snakes excrete rarely, and that collectors and exhibitors have permanent and exclusive contracts with the big pharmaceutical companies. He goes back to the chicken shit, but notwithstanding all efforts shit remains just shit, resisting all attempts to transform it otherwise.

Again, there is a general point that I want to make through this story. Unlike 'Chromium', 'Nitrogen' is a story that is conditioned by commercial competition and an emerging international commodity market, in this instance in cosmetics, where aesthetic value links closely to material properties – not just of materials but of materials reacting with a warm, living and material human body. The work of the chemist here is not to recover lost value, but to reproduce – through the techniques of analysis and synthesis – the desired qualities of the market leader (even better them), without being the same as the market leader, for to be so would be to infringe the patents held by competitors. In this world of material mimicry and mimesis, the industrial chemist is potentially king. Except, as this story illustrates, things do not always work out as intended, for synthesis is a devilishly difficult task to perform, even more so – as here - within organic than inorganic chemistry. As Bensaude-Vincent & Stengers (1996) explain:

> "One main constraint of the chemist's game is that he cannot act directly on materials. He has to delegate operations, to entrust them to intermediary molecules put to work in a flask. Their activity must be directed to a definite site in the molecular structure, to break a bond here, form another there. This requires constant tweaking and great skill, for each time a reagent is introduced, it tends to operate everywhere indiscriminately. [...] The synthetic chemist therefore has to invent a device to limit its activity, design a pathway and drive the reaction as a function of the available reagents. The precise order in which the different reagents enter the process has to be determined, the stages managed, and intermediaries with protective groups ("scaffolding" constructed to maintain certain pieces of the structure intact while the others are being worked on) created. It is an art in which delegation – letting reagents react – and manipulation – getting them to act where and as one wants – are required" (p 157).

It is here then, in the world of synthesis, that we see where a materiality that comprises molecules really does matter economically; not in some abstract sense, but in the very particularities of trying to control the process as well as the products of synthesis for commercial ends. The value of Levi's story for us is that it shows that synthesis doesn't always work; material transformations, particularly – although not exclusively – where they concern attempted product innovation are not guaranteed – a point which tends to be overlooked in work that concentrates on patented materials. Rather, this process work can be boring, futile, and ultimately lead nowhere. Shit remains just shit – but the possibility that it might be turned into metaphorical gold ensures that such (experimental) work continues to be done.

'Chromium' and 'Nitrogen' weave stories that depict the life of the industrial chemist in the service of capital (see too Bensaude Vincent & Stengers, 1996). Positioned 12th and 16th in the story series respectively, they show a confident chemist drawing on stocks of theoretical, experimental, technical and practical knowledge of materials to attempt to reconfigure unknown and/or unruly materials in assemblages that either reclaim value (where this has been lost) or constitute value (in the form of a new commodity). 'Chromium' works – in the sense that Levi succeeds in the tasks set, achieving the configurations required; 'Nitrogen' fails, with material remaining as 'foul vapours' and 'a black and murky liquid', and there are other element stories which insist that failure is as much a part of this working life as the successes that are patented (see 'Tin'). As earlier chapters show, though, knowledge of how to work with uncertain materials, how to deal with defects and impurities (along with the discipline of how to work with and handle materials) is learnt. Indeed, together the earlier element stories in *The Periodic Table* constitute a pathway, of learning the practice of chemistry, from the earliest, chaotic experiments of two young boys with glass and 'laughing gas' in a makeshift laboratory ('Hydrogen'), through formal education and the assessment of individual's theoretical and practical knowledge at school and university ('Zinc', 'Iron'), to the initial world of (supervised) employment ('Potassium'). Levi's point therefore is that ways of working scientifically with materials are never constant but mediated by the life course – a line of thinking he pursues most profoundly in the closing element story, 'Carbon'.[3] In the interstices of the text, however, lie other ways of working with materials – those of factory shift workers.

### *Sulphur – or a tale of near disaster averted*

"With a jump he was on his feet, his ears listening tensely and all his nerves in alarm. The clatter of the pump had suddenly become slower and more clogged, as though constrained [...] the needle of the vacuum gauge, like a threatening finger,

[3] 'Carbon' is Levi's final element story, where he pursues the question of whether it is possible to speak of the life of an atom, in so doing addressing the temporalities of human and non-human material life. In telling the story he answers his question in the affirmative, recounting an imaginary journey of an atom of carbon from the point of photosynthesis, through a vine, the drink of a runner's body that is exhaled, to a cedar tree, woodworm, a moth .. The story's end is with the drinking of a glass of milk, the travel of carbon to Levi's brain and its representation as in charge of the material act of writing – of a hand moving across paper, a path comprising energy and impression, but which is simultaneously signs on paper, words and things. It is also perhaps worth adding here that it is being a chemist that saved Levi's own life in Auschwitz: 'Vanadium' is an extraordinary story which entwines collective and individual memory and responsibility through paper and materials exchange.

*rose up to zero, and look! degree by degree it began to slide to the right. That was it, the boiler was building up pressure.*
*"Turn it off and run". "Turn everything off and run". But he did not run […] Lanza was in a frenzy to open the hatch and let the pressure escape; he began to loosen the bolts, and, look! a yellowish slime squirted hissing from the crack together with puffs of foul smoke: the kettle must be full of foam. Lanza slammed it shut, filled with an overwhelming desire to get on the phone and call the boss, call the fireman, call the Holy Ghost to come out of the night and give him a hand or at least advice"* (pp 162 – 3).

Lanza is no Levi. He is a night shift factory operative who spends his working hours dreaming, thinking about what matters for him (family, home, his plans for his small holding, the local tavern), semi-dozing and smoking. Work for him is mainly about money, but to make money requires that Lanza sell his labour power, that he works: with particular materials (in this case sulphur), with various plant infrastructure and technology (here, a motor, furnace, vacuum pump, siphon pipe, compressor and collection basin), and with plant monitoring devices (thermometers, gauges, needles). Lanza then, is a means for Levi to illuminate a very different chemistry work to the life of the scientist in the employ of capital. In 'Sulphur' therefore is depicted a world in which materials are known not through scientific knowledge and practice but through the senses – through smell (the "dirty, sad smell" of sulphur that "even the dogs don't like"), colour (in this case, whites and blacks), and sound ("a long, angry hiss, which gradually calmed down into a rustle, a murmur and then fell silent") – technologies through practical knowledge, know-how rather than knowledge-of. We read here of a man who knows that certain pieces of machinery are faulty, and what to do to avoid being injured by them (a motor that backfires when ignited), and that certain temperature gauges are inaccurate (and so should be ignored). At the heart of the story, however, is the moment when the process goes out of control. Levi's panic-striated, embodied account eloquently re-lives Lanza's moment of terror and his utilisation of practical knowledge to bring the process back under control. But in its ending lies a quieter terror, altogether more muted. In handing over to the day shift operative, Lanza makes no mention of the faulty process, merely pumping up his bicycle tyres and going on his way.

The general point that Levi is making here through the cipher of Lanza and his story's end is that of labour's alienation and its potential effects when working chemically with materials. This is a theme that resonates strongly elsewhere in our programme – notably in relation to Project 2, but also within Projects 1 and 3. Practical knowledge, such as that Lanza draws on, may be able to resolve the crisis and bring the process back under control, but this is not always the case – witness the Windscale Fire of 1959 in the UK, Chernobyl or the explosion at the Union Carbide plant at Bhopal. More broadly therefore 'Sulphur' works as a moral story for chemists and industry, as well as a morality tale. It reminds us that plant scale material transformations retain the potential for process to go out of control, and that the effect on life (alienated life particularly) is likely to be catastrophic; it cautions against the dangers of routinised, habitual working practices and workers' lack of scientific knowledge in relation to chemical processes, whilst quietly celebrating the heroic practical knowledge of the Lanza figure; and it invites us to reflect on the morality of a worker who cares only for himself and not for the potential safety of his fellow workers.

‘Sulphur’ however, also contains important lessons for how we might recognise the importance of material in conceptualising economies. Here I would make three points. First, with the inordinate attention given to product, the potential for process to go out of control has been seriously overlooked. The importance of process has already been highlighted in respect of my previous discussion of synthesis. So – to follow through – what this seems to require is a shift in object, which acknowledges that products emerge from assemblages and sequencing of materials, technologies and multi-faceted levels of activity including that of scientists and operatives. If that sounds like an argument for a practice-oriented understanding of economy, with more than a few debts to STS along the way, then it is just that – no apologies! However, sequencing here implies no automatic assumption that all will occur as it should do. Rather, and in line with an account that takes practice seriously, I would argue that we need to pay far more attention to those moments when process goes awry. John Law’s wonderful study of the TSR2 (Law 2002) provides one exemplar of how this might be done, but I think we can and need to push work away from the purely experimental and scientific setting to the plant setting; to work with Lanza, and to focus on moments where material transformation at the level of plants goes awry. This may, as with Thorp, be a matter of leakage, but equally it can be about material transformations becoming unstable, even irreversible. Such ‘incidents’ – long the preserve of more overtly environmental research (usually focused on pollution) – need to be reclaimed as economic phenomena too – and materials’ effect on future plant practice (be this in terms of process or labour) charted.

My second point goes back to Lanza and practical knowledge. Overlooked again through STS’s emphasis on scientific knowledge and practice, the knowledge of labour is of critical significance to furthering accounts of material within plant settings. This is not to value such knowledge over and above scientific knowledge, but it is to insist that working practically with particular materials brings with it certain habituated understandings of how to work with specific materials, equipment and machinery. In some instances habitual working practices (often described as plant cultures) can prove troublesome – Thorp, again, is the exemplar case. But in other instances such knowledge is of prime importance to realising value from both materials and machinery. Thus, Lanza’s actions are simultaneously the means of saving his own life, of saving the plant from an explosion, of saving the capital tied up in this plant and of realising value in the form of the commodity. Whilst such might not be an everyday occurrence, actions such as this are familiar enough, whilst at the day-to-day level it is certainly the case that practical knowledge about what to do with certain ‘mixes’ to achieve the desired material state (add a bit more of this; stir more; heat for slightly longer) are part and parcel of what is absorbed through a working life spent in proximity with particular materials, elements and molecules. Difficult for capital to codify – although acknowledged to exist – such knowledges are as difficult for academics to access, in that they are tacit, barely spoken, possibly unarticulated even. They are therefore not particularly amenable to the standard methods of working academically in plant settings. Furthermore, as challenging is to understand what know-how actually is and to work out appropriate ways of representing such material knowledges. If material is to be taken seriously within the labour process, however, it requires we find ways in which to do just this.

The third and final point I want to make concerns Health & Safety. The factory in which Lanza is described as working is a world where H&S is barely present; whilst he wears a basic mask when handling the sulphur packages, Lanza's work involves sidestepping backfires, ignoring faulty gauges and using the materials that are to hand, notably tools and implements, to improvise in his attempts to bring process back under control. This then is a relatively unmediated, unprotected world of work, where bodies and materials are both proximate and likely to be 'in contact', often to dangerous degrees. With the advent of enhanced H&S procedures in certain parts of the world, human bodily contact with particular materials, proximity even, has undoubtedly diminished. In its extreme form, for example in a nuclear waste processing plant, this involves the use of automation and robotics in the production process; elsewhere arrays of protective materials are used to seal the body against the capacity of particular materials to penetrate body tissue. Overalls, hard hats, protective goggles, gloves, hard cap boots are all standard issue on-plant in the steel industry for example. In certain 'hot' areas of N-waste plants however, it is the PVC suit with breathing apparatus that defines a working body (Zonabend, 1989). I suggest that it is here, in the materiality of the 'cloth' that adorns the industrial labouring body, that we find a further dimension to how material matters economically – as the means to ensure not just against accidents and injury, but to keep the workforce working, by shielding bodies from material's ever-present capacity to permeate skins and be absorbed by tissue.

'Chromium', 'Nitrogen' and 'Sulphur' all show how material figures in working lives in the chemical industry, and its significance for enhancing conceptualisation of labour, value and the intra-plant production process. They also insist that process – that is material transformation – is critical to thinking about materials, that is, that it is insufficient to think material through product alone. Moreover, processes of material transformation emerge here not just as routine, unexceptional events but as potentially unstable and, at least in 'R&D' terms, unworkable (in the sense of refusing to do what theory suggests they should do). Levi's text, then, quietly insists on a performative economy, in which material transformations – even those that have been standardised as part of the production process – are continually being re-made in the moments of their 'going-on'. At the same time, it establishes that the products of chemical processes are best thought of as manufactured assemblages, constituted in turn through assemblages of scientific and operative knowledge and practice, materials and process technologies. As both 'Chromium' and 'Nitrogen' disclose, these assemblages themselves constitute a manufactured durée in products; that is, they use the known properties of certain material combinations to produce not just a particular commodity (with a particular exchange/use value), but a commodity that is defined by the extent of its material stability. To return to my general arguments, what this confirms is that it is particular configurations of atoms and molecules, their bringing into being and the temporalities of their holding – rather than general principles – that matters to taking materials seriously in political economy.

For all the insights it undoubtedly sheds, there are limits to the work to which *The Periodic Table* can be put. These are precisely about its strengths; a text that is about a life and the lives of entangled others, can only ever illuminate the intricacies of material at the level of single plants and their connections through the supply chain. If we are to explore how contingency works itself out more generally within the chemical industry, then we need to look to some rather different sources. In the following section, therefore, I draw on Bensaude-Vincent & Stengers' *A History of Chemistry*, focusing particularly on the Leblanc process. An innovation that was widely adopted in England as well as France in the early C19th, the Leblanc process enables us to see how contingent experimental learning with materials translates between, and, indeed, transforms, fields.

**4: Processes in landscapes: Leblanc, soda and the importance of by products**

> "On September 25, 1792, (Nicolas) Leblanc obtained one of the first patents approved under the legislation on industrial property voted by the Assembly. It described how to make sea salt react with sulphuric acid in a large lead receptacle, whose cover was fitted with a pipe for releasing hydrochloric acid, and, then, how to mix the sodium sulphate thus obtained with charcoal and limestone and heat them in a reverberatory furnace to produce raw soda" (Bensaude-Vincent & Stengers, 1996, pp 161 – 2).

The Leblanc process was a defining moment in the history of chemistry. Significant not just in terms of its specificity, its key innovation was to develop the first synthetic material (Bensaude-Vincent & Stengers, 1996). Rather than extracting soda from sea salt, then, Leblanc made it, fabricating it from a sequence of specific transformations involving particular assemblages, materials and their properties. The importance of synthetic materials for subsequent industrial development is hard to over-estimate. In short, the development of synthetics facilitated industrial expansion, enabling both absolute increases in the volume of product output and product diversification; disrupted the hitherto close affinities between industrial location and the geographical occurrence of naturally occurring materials; and eventually opened-up a whole new relationship to materials, providing the basis for thinking about materials not just as substitutes or replacements, but as 'informed materials' (Bensaude-Vincent & Stengers, 1996; Barry, 2005). Such points are vital to any general consideration of how material matters economically, disclosing the degree to which a material logic continues to matter, particularly for certain industries, and how understandings of material are themselves transformed through the process of chemical R&D. Nonetheless, there are further points to be gleaned from a close examination of the Leblanc process. Specifically, I highlight two: first, that the importance of the Leblanc process is not just in the manufacture of soda, but about what built up around the soda works, and, secondly, that focussing on process is critical to developing understanding of material transformation, moving it away from an exclusive focus on the becoming of an end product, to encompass the altogether less visible world of by-products and their relation to waste and value.

The social science literature on the development of industrial capitalism is replete with the seeming obligatory references to contemporary descriptions of landscapes (and bodies) violated and assaulted by industrial development. Depicted by C18th and C19th liberal and moral social commentators as literal manifestations of Dante's *Inferno*, these writings are redolent with sensory horrors; choking, acrid smoke, flames that shoot skywards, the stench of sulphur, and the despoliation of excavation and its aftermath. In this the soda works is no exception. "Seen from a long distance away, the air appeared to be tinged with reddish vapours and dust, which became acrid, irritating, and nauseating as one approached […] one would think oneself to be on the rim of a volcano" (Bensaude-Vincent & Stengers, 1996, p 160). Or, "the herbage of […] fields in their vicinity is scorched, the gardens neither yield fruit nor vegetables; many flourishing trees have lately become rotten naked sticks. Cattle and poultry droop and pine away […] and when we are exposed to it, which is of frequent occurrence, we are afflicted with coughs and pains in the head" (Wikipedia).

Powerful as the volcano metaphor is, however, its capacity to illuminate a manufactured landscape is restricted. Indeed, to fully understand this landscape, one needs to appreciate the material transformations that are performed by the Leblanc process. This is most readily understood through the following mass balance equations:

$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$ (Step 1)

$Na_2SO_4 + CaC0_3 + 2C = Na_2CO_3 + CaS + 2CO_2$ (Step 2)[4]

Here we see that making sodium carbonate has other material effects, notably the production of hydrogen chloride gas (Step 1) and calcium sulphide (Step 2). Indeed, for every 10 tons of soda produced the Leblanc process generated 7 tons of hydrogen chloride and of calcium sulphide. The landscape of the soda works, then, is more accurately understood as a landscape of by-products, respectively released into the air (and later water courses) and dumped in piles of solid, smelly waste (note 4). What is acrid and irritating in its effects, then, is the presence of hydrogen chloride gas; the nausea is in turn an effect of sulphur's vapours; and indeed, the absent presence that is the smell of hydrogen sulphide lingers on, not just in the dumps of weathering calcium sulphide around the soda works, but through the subsequent isolation of sodium carbonate itself, through filtration, washing, evaporation and crystallisation (note 4), and in the consumption of the salts themselves.

Beyond specifics, the general point is clear: manufacturing materials produces more than the desired end product itself; or, in other words, what goes in will come out, albeit not necessarily in its original form, as atoms and molecules bond (or not) in the processes being enacted. Conventionally thought of as by-products – and therefore largely dismissed by a social science where the end product has always mattered most – these additional products have been highly significant economically. To continue with the Leblanc example: what grew up around the soda works, much of it initially in

[4] The mass balance equations mask a series of processes. A batch process, Step 1 of the Leblanc process involves mixing sodium chloride and sulphuric acid and then subjecting to a low heat. Hydrogen chloride gas is produced, along with a fused mass, which is further heated to evaporate off any remaining chloride to produce sodium sulphate. Step 2 involves first mixing the sodium sulphate with crushed limestone (low in magnesia and silica) and coal (low in nitrogen – otherwise cyanide forms), and then heating in the reverberatory furnace. The result is a solid mass, of sodium carbonate and calcium sulphide. Sodium carbonate is separated out from calcium sulphide through the lixiviation process, involving sequential cascaded washings of the solid mass ('black ash') in water. Carbon dioxide is then blown through the resultant liquid, precipitating the calcium and volatising the sulphide to produce hydrogen sulphide gas. The liquid is then separated from the precipitate and evaporated, with the resulting ash being re-dissolved into a concentrated solution in hot water. Any remaining solids are then separated off, and the solution is cooled to recrystallise as sodium carbonate decahydrate. The solid calcium sulphide waste had no economic value initially and was dumped in the immediate vicinity of the works, where it weathered to produce hydrogen sulphide gas – and the smell of rotting eggs.

response to anti-pollution legislation, was a whole technological complex.[5] Upstream, once a means of converting hydrochloric acid to chlorine gas had been established, hydrochloric acid was hived-off to produce chlorine, which in turn was used to manufacture bleaching products for the burgeoning textile industry. Downstream, the scaled-up production of sulphuric acid was enabled by the recovery of acidulated water from a tank below the lead receptacle used for step 1 of the process.

Instantiated in multiple locations in Northern England in the latter half of the C19th, the Leblanc process, and its related material transformations came to characterise whole areas of Lancashire and Tyneside, as well as Clydeside: “small tranquil villages had become foul industrial boroughs crowded with workers […] a development (that) may be traced to England’s industrial needs: first textiles, glass and soap, then paper and fertilisers consumed large quantities of acid and bleaching powder” (Bensaude-Vincent & Stengers, 1996, pp 168). Further, by 1870 UK production of soda via the Leblanc process has reached 200,000 tons, greater than the combined figure for all other soda producing countries. The development of synthetic materials, then, not only laid the foundations for the development of the mass production that fuelled industrial capitalism, but its material manifestation in various inter-connected plants in turn worked to generate what we now think of in terms of industrial agglomerations and districts. In a very real sense then, particular economic geographies of production and place are not just about the production of particular commodities but also about the materialisation of process(es) of material transformation in place.

I will come back to flag some of the implications of this last point in the conclusion to this paper. Suffice to say that the subsequent history of chemistry is characterised by further similar developments to what grew up around the soda works – as the thick black coal tars produced as by-products by the cokeries became the basis for the synthetic dyes that transformed late C19th European clothing (mauve, fuschia, magenta, indigo); and as the manufacture of dyes themselves opened-up a raft of other synthetic potentials, including plastics and pharmaceuticals. Flow charts of UK chemical industry giants such as ICI in the 1970s (North, 1975) give some idea of the complexity of contemporary synthesis, but they pale into insignificance alongside those of Bayer, BASF and Höcsht, for whom the patenting of synthetic dyes and subsequent R&D work provided the pathway to manufacturing key pharmaceutical products, and indeed the development of notions of ‘informed materials’. Echoing Primo Levi’s experiments with chicken shit and lipstick, Bensaude-Vincent & Stengers give a glimpse of this chemical R&D world in their discussion of the development of the German chemical industry in the early C20th. Here the purpose was not just to work on improving the end product and on developing alternative technologies of production, but simultaneously to unlock any potential/s that may (or may not) lie with intermediary products. My sense is that their tantalisingly brief insight is itself of profound significant to our concerns. In short, it highlights two key points: 1) that value can potentially be realised from all material brought within a particular set of transformations, not just from the final commodity; and 2) that labour is directed to uncovering (and eventual patenting) the potential of all material caught within a particular frame – in this case, of the German chemical giant BASF. Following through, where we are here is not with the dumping of material as waste

[5] The first of several Alkali Acts was passed by the British parliament in 1863, specifying that < 5% of hydrogen chloride gas could be emitted by alkali plants (i.e. soda works).

(as with the early Leblanc soda works) but back in the terrain of the importance of material as assets of zero value (i.e. with Levi and the livered paint). What matters here, clearly, is to maximise the value in the materials present within the bounds of the firm; to fully realise the potential for value creation; and to ring fence the potentials realised. To focus purely on end-point commodities then (or even on these and any by-products sold) is to miss that the value in materials is *uncertain* and *potential* as well as known; that potential value is growing ever more complex and open ended with the development of informed materials; and that certain forms of work at least (notably chemical R&D) are bound up in realising potential value, and therefore have a different relationship to value than that suggested by conventional labour theories of value. At best separated from the immediacy of their labour, at worst (as with the shit that remained just shit), divorced from any realisation of value, such work is the ultimate in productive yet unproductive labour, in which knowledge itself works to constitute material limits, as the point where value resists realisation.

Where this takes us, I think, is to a more heightened awareness of just what is at stake when material transgresses capital's bounds. This moment, when material literally is intentionally (as opposed to unintentionally) wasted, for example, discarded as effluent, disappearing up a smoke stack, released from an outflow, is the moment when material's potential is lost to *particular* capitals. No longer material of zero value, caught within the territorial and/or proprietorial confines of a firm, physical release marks the ultimate loss of value for an organisation, for, in this material flow to the outside, what happens is a return to conditions where others might appropriate. To give an example: there is a rather ironic twist to the story of the Leblanc process. Early in the C20th, this process was ousted economically by the Solvay process. Producing vastly greater yields of manufactured soda than the Leblanc process, the Solvay process was itself developed from the literal wastes of late C19th gas factories. Coal tar and ammonia waters dumped in copious quantities in streams and water courses were the key materials with which Solvay worked. Whilst we might note the potential allure of both prizes and patents in focusing Solvay's mind on how to work with Berthollet's laws to deal with ammonia residues, the general point here is that material discarded as waste is up for grabs for anyone to work with (and patent). To discard therefore is to pass over such potential. Going back to chemical R&D then, working on material of zero value is capital's means both to retaining potential intellectual property and to preventing its development by others – fundamentally, it is about the possession of the rights to value.

## 5: Conclusion

To attempt to conclude this paper in any formal sense seems premature. Rather, using the chemical industry as my exemplar, my primary aim here has been to open up discussion of how material matters to economies, and – relatedly – to think about how we might accommodate materials more vitally within our conceptualisations of economies. In particular the paper highlights five points: the importance of process, and not just product, to understanding material transformations; that material, in the form of intermediary and by-products as well as material of zero value, has potential as well as actual value – and that this potential is the site of active work for many in R(&D); that working with materials is as much about know-how as knowing about, that is, it entails practical knowledge as well as theoretical knowledge; that transformations are particular, contingent and purposeful, even if they always have unintentional consequences or side effects which themselves are of critical economic importance; and that 'H&S', in the form of the adorned working body as well as regulatory practices, is of fundamental importance to understanding materials and their materialisation in the workplace.

In the interstices of the paper, however, is one further important sense in which material weaves its effects. Neither product nor process, this is as assemblages of plant (of infrastructure, tools and machinery) that work to effect particular transformations. In short, what we conventionally think of as the black box of 'fixed capital'. Except that when we open up this black box it is a veritable Pandora. In her probing study of the French nuclear industry, Gabrielle Hecht (2001) illuminates how 'technopolitical regimes' are themselves materialised, not only in particular technologies (in this case, nuclear power, gas graphite and light water reactors) but also in the entire design and configuration of a specific plant and its processes. Further, she shows how these configurations constitute limits, not just to the obvious (outputs i.e. electricity and plutonium) but in terms of what it is possible to do with particular materials in certain assemblages. The meltdown of the Saint Laurent EDFX reactor is an exemplar case. Design, both of plant and of systems, materialises; it insists on handling certain materials and working with them in particular, often highly restricted, ways, and in ways that are temporally and spatially sequenced. Moreover, to attempt to reconfigure particular situated systems and plants (to change process, to enhance output, to increase the diversity of the product range …) poses further problems in sequencing that are themselves addressed more often through the addition or replication of capacity than by its substitution. This is a spatial fix that works only to entangle further particular places with particular industries. Yet, whilst capital ultimately shifts to more productive places, the legacy of such materialisations is all around us, particularly in the landscapes of the old industrial regions – as 'mothballed capacity', as 'brown-field' sites, and increasingly in the work of decommissioning. The latter – a process that is simultaneously cleansing and wasting, and that fundamentally is about the disassembly, removal and/or displacement of engineered products, systems and plants – is one of the growth businesses of the C21st. At the heart of the relation between waste and value, these industries (together with the sites they operate in) are central to our programme. Indicative of capital's ceaseless quest for new markets on the one hand, on the other they pose a radical challenge to accounts that see materialisation merely in terms of product innovation, or even day-to-day operations. As with the chemical industry, they insist that material transformation (even in the mothballed state) is always going on and that economies are about the bringing into being, holding and release of particular configurations of atoms and molecules over varyingly attenuated durées that are both manufactured and unravelled. In their unravelling, however, they are always becoming something else – for matter can never be undone, just atoms and molecules unbound and rebound.

**References**

Barry A (2005) Pharmaceutical matters: the invention of informed materials *Theory Culture and Society* 22: 51 - 69

Bensaude-Vincent B, Stengers I (1996) *A History of Chemistry* Cambridge MA: Harvard University Press

Gille Z (2007) *From the cult of waste to the trash heap of history: the politics of waste in socialist and post socialist Hungary* Bloomington: Indiana UP

Gordon R (Ed. 2007) *The Cambridge Companion to Primo Levi* Cambridge: Cambridge University Press
Hecht G (2001) *The Radiance of France: nuclear power and national identity after WWII* Cambridge MA: MIT Press
Hudson R (2001) *Producing Places* London: The Guilford Press
Hudson R (2005) Rethinking change in old industrial regions: reflecting on the experiences of N E England *Environment and Planning A* 37: 581 – 96
Hudson R (2008) Material matters: taking cultural political economy to the next level *The Waste of the World* Working Paper Number 1
Law J (2002) *Aircraft Stories: decentering the object in technoscience* Durham NC: Duke University Press
Levi P (1985) *The Periodic Table* London: Abacus
Miller D (Ed. 2005) *Materiality* Durham NC: Duke University Press
North G A (1975) *Teesside's Economic Heritage* County Council of Cleveland
Pickering A (1995) *The Mangle of Practice: time, agency and science* Chicago: Chicago UP
Thomson I (2002) *Primo Levi* London: Vintage
Zonabend F (1989, 1993 translation) *The Nuclear Peninsula* Cambridge: Cambridge University Press