Why History Matters in Understanding the Social Issues of Nanotechnology and Other Converging Technologies

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Introduction: Why There Isn't Enough Nano-History

People often laugh – nervously – when I tell them I work on the history of nanotechnology. The idea is funny – nano is new and revolutionary, wholly lacking in history. They often ask "how can you do the history of something that's only five years old?" The awkwardness of nano-history is even more pronounced in the policy context. Even though there is plenty of funding for research on the "ethical, legal, and social implications" of nano (in the U.S., the National Nanotechnology Initiative has mandated that about 4% of the $1 billion in annual federal funding for nano research be set aside for ELSI work), there is very little funding for historical research on nano that extends further back than the founding of the NNI in 2000.

In part, this paucity is due to the conservative nature of history. There are many historians of science whose work would be relevant to nano-studies, but whose reaction to nano-hype, quite reasonably, is "there's nothing new here, so why should I buy into the charade?"[1] But the ahistorical nature of most ELSI work is mostly due to the structure of

[1] For an excellent overview of why "there's nothing new here" is a reasonable response, see Litton, Paul (2007) "'Nanoethics?' What's New?," *Hastings Center Report* 1: 22-25. Nano-hype has generated a cottage industry in the nano-studies community. See Berube, David (2006) *Nano-hype or the Truth about the Nanotechnology Buzz* (Amherst, NY: Prometheus Books); and the less sensational Toumey, Chris (2004) "Narratives for Nanotech: Anticipating Public Reactions to Nanotechnology," *Techné: Research in Philosophy and Technology* 8.2: 88-116.

nano funding and the organization of the academy. I base my analysis here on the United States, but conditions are similar elsewhere. In the U.S., the National Science Foundation's strategy for all of nanotech has been to found large centers on university campuses to act as national user facilities or specialized "centers of excellence." This strategy makes some sense in the historical arc of nano. The current network of centers is descended from academic sub-micron fabrication facilities founded in the late '70s and, further back, from Materials Research Laboratories founded in the '50s (the new centers are also meant to fill a niche left vacant by the demise of once-dominant large corporate research facilities such as Bell Labs).[2]

The problem is, the NSF wants to apply the logic of big campus centers across the entire disciplinary space of nanotechnology as if they were a universal good. This creates two entry points for work in social studies of nanotechnology, one of which is particularly uncomprehending of the epistemic cultures of history, sociology, and science studies.[3] The more conducive route is through the Centers for Nanotechnology in Society at Arizona State University and at the University of California – Santa Barbara (along with smaller groupings at Harvard and the University of South Carolina). The NSF has set these up as social science equivalents of its other centers. That is, the CNS is meant to act in the same way as places like the University of Pennsylvania's Nano-Bio Interface Center or Northeastern University's Center for High-Rate Nanomanufacturing. Keep in mind, though, that a major motivation for these other Nanoscale Science and Engineering Centers (NSECs) was to house large, expensive pieces of equipment that researchers

[2] Jim Murday, interview with author, July 8, 2002 (Washington, DC); Leslie, Stuart W. (1993) *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press).
[3] Knorr-Cetina, Karin (1999) *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge, Mass.: Harvard University Press).

from around the world could to travel to and use.[4] The only comparable piece of "equipment" for history and social science would be space and staff for archival documents – something that would be quite useful, but that the NSF would never fund. So while large centers can be useful to natural scientists, their utility to social scientists and historians has yet to be made clear.

The engineering and natural science NSECs also provide the second, less conducive, opening for social studies of nano, in that they are each required to have an ELSI component.[5] This latter strategy, especially, is almost guaranteed to fence out history. Imagine that you are a materials scientist or a biophysicist, struggling to corral your colleagues into writing a proposal for a big NSF-funded nano center on your campus. Suddenly, the NSF says that you need some people on the grant who can do "ethical, legal, and social implications" research. Most likely, you are a little put off and perplexed by the NSF's requirement. You "know" that the social sciences and humanities are completely different from the sciences; you don't really know what they do and have only a vague notion of why they might be useful. You do "know" that the underpinning of certain knowledge is quantification, and therefore you prioritize collaborations with social scientists who work with numbers.[6] Or, perhaps, you believe the ELSI requirement is not intended/able to produce *certain* knowledge and therefore

[4] Jay Harris, interview with author, May 5, 2006 (San Diego, Cal.); Ed Wolf, interview with author, May 26, 2005 (Ithaca, NY); Hank Smith, interview with author, October 25, 2005 (Cambridge, Mass.).

[5] National Science and Technology Council (2006) *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry: Supplement to the President's 2007 Budget* (Washington, DC: Office of Science and Technology Policy). This document outlines all the federal money being spent on nano research, as well as the NNI's strategy for coordinating that spending. Pages 25-33 specifically focus on ELSI funding strategy.

[6] A viewpoint nicely deconstructed in Porter, Theodore (1995) *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton: Princeton University Press). From reports of PI meetings, it appears that the NSF shares this dislike of qualitative, empirical work and would prefer ELSI researchers either provide numbers (even if those numbers tell little about the social context of nano) or ethical advice (even if that advice is not rooted in empirical understanding of nano).

you prioritize collaboration with colleagues whose output you believe is commentary (English, comp lit., art) or debate (philosophers, rhetoricians) rather than empirical (if qualitative) facts.[7]

Moreover, what really worries you (and the NSF) about "social implications" is that the public will reject nanotechnology. Thus, you are willing to fund anyone with an instrument to poke and prod "the public" into revealing its attitudes.[8] It doesn't particularly occur to you to have someone poke and probe the researchers within your own center to discover, at the microsociological level, what the social context of nanotechnology *research* is. Work that is empirical and field-based, yet qualitative and narrative-centered, slips through the cracks. In particular, rich historical and ethnographic research simply does not get on the radar.[9] For instance, at the NSF meeting of all the principal investigators in the area of "societal implications of nanotechnology" in March 2007, only *two* of the 36 PIs in attendance were housed in history departments; of the other thirty-four PIs, only a further two (by my count) have done work that is historical in scope.

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[7] My characterization is a little unfair, but not much – it's based on numerous conversations with practicing nanoscientists, some of whom have had to go through the process of finding ELSI collaborators that I describe.

[8] Hence the large number of surveys of public attitudes toward nano, such as Kahan, Dan M. *et al.* (2007) "Affect, Values, and Nanotechnology Risk Perceptions: An Experimental Investigation," *Cultural Cognition Project Working Paper No. 22*. Results of such surveys are usually trumpeted with headlines like "surveys finds emotional reactions to nanotechnology" – even though the major finding (usually buried in the small print) is that 80% of those surveyed have no idea what nano is.

[9] I know that a few nano centers have tried to employ ethnographers. So far, these efforts seem to have foundered on a mutual incomprehension of ethnographer and center administration as to what such an ethnography would look like or how it would be done. As an indication, at the 2006 Social Studies of Science conference, a panel on "New Ethnographies of Nanotechnology" ended with the commentator, Ros Berne, quite rightly observing that none of the presentations was actually an ethnography! Ethnographies which have arisen out of the investigator's intrinsic interest in a specific topic (rather than in "nano" more generally) show more promise: see, among others, Johannson, Mikkael (2003) "'Plenty of Room at the Bottom:' Towards an Anthropology of Nanoscience," *Anthropology Today* 19:3-6 and Roosth, Sophia (2006) "Sonic Eukaryotes: Sonocytology, Cytoplasmic Milieu, and the *Temp Intèrieur*" (Vancouver: talk at Society for Social Studies of Science meeting).

Now, imagine that you are one of these 32 or 34 non-historian PIs (an ethicist, an economist, a political scientist, etc.) who have been enrolled into your local center's ELSI effort. You've probably never heard of nanotechnology before; almost certainly you don't know very much about it. You get a thumbnail description from your nano colleagues, who make it sound very new and exciting and revolutionary. If they mention the history of the field at all, they may cite Richard Feynman and the scanning tunneling microscope. In all likelihood, they neglect to mention the long incubation of nano in the '80s and '90s, when the pioneering figures were either oddball futurists or grant officers slogging through the bureaucratic infighting needed to create the NNI, either because your colleagues are unaware of that story or because they find that era vaguely seedy and embarrassing.

In any case, you are given the impression that nano has no history. And, for your pragmatic purposes, it doesn't. Before 2000, neither you nor (almost) anyone else was interested in social studies of nano; after 2000, pots of money started to appear that got lots of people interested.[10] You can be forgiven for thinking that pre-2000 doesn't matter. What I'll argue here, though, is that neglecting the history of nano is like trying to understand terrorism without understanding events before 9/11 – just because more people are paid to look into a problem after a certain date doesn't mean that events prior to that date aren't crucial in grappling with events today. Quite the opposite. Not that research oriented to the present, future, or very very recent past isn't vitally important. But without historical perspective, it's easy to be trapped into thinking that the

[10] See Bennett, Ira and Daniel Sarewitz (2006) "Too Little, Too Late? Research Policies on the Societal Implications of Nanotechnology in the United States," *Science as Culture* 15: 309-325. As we will see, though, in their rush to dismiss science studies as "nowhere to be seen" Bennett and Sarewitz make a critical category error – they assume they can measure science studies' interest in nanotech by looking for research explicitly about "nano." This accepts the radical novelty of nano and therefore ignores the wealth of historical and sociological research on the fields that were nano before there was nano.

mechanisms, institutions, motivations, and actors of nano are in place for the transcendant, highly rational reasons that they claim to be, rather than for the ordinary (though still reasonable) reasons bequeathed by history.[11] There needs to be funding for a spectrum of research, from nano's deep past to its present and future.

To some extent, that spectrum is better represented at the two Centers for Nanotechnology in Society (and the two centerlets), particularly at Santa Barbara and South Carolina.[12] There is a significant problem with the CNS model, though. Because funding is funneled through these centers, the NSF has effectively fenced out an enormous reserve of nano expertise. There are, quite literally, *hundreds* of historians, sociologists, and anthropologists of science and technology whose research concerns exactly those fields which today are being drafted into nanotechnology – historians and ethnographers of materials science, condensed-matter physics, chemistry, molecular biology, mechanical engineering, electrical engineering, computer science, etc. etc.

These people are given little incentive to make their work relevant to social studies of nano; and the political scientists, economists, etc. who do ELSI work for the NSECs have little incentive to seek out these people's expertise. Hence, only a handful of historians and sociologists have actually gotten involved in social studies of nano. In fact, many of them find social studies of nano laughable or vaguely disreputable. Consequently, we have a vast body of knowledge *about nano* that simply doesn't hook up to the new knowledge being generated in nano-studies. A wiser system than centralization through the CNSes would've been for the NSF to keep an eye on *all*

[11] This is a variant of what is known in sociology as "garbage can theory." See Cohen, Michael D., James C. March, and Johan P. Olsen (1972) "A Garbage Can Model of Organizational Choice," *Adminstrative Science Quarterly* 17: 1-25.
[12] Truth in advertising – I collaborate extensively with Working Group 1 at the Santa Barbara CNS, which is dedicated specifically to historical research. I've also worked closely with those doing historical studies at South Carolina, particularly Chris Toumey, Ann Johnson, and Davis Baird.

history, sociology, and anthropology proposals to go through its Science and Society program and flag those that had even a peripheral relevance to nano. Those proposals could have been funded (in whole or part) from nano-ELSI money, with the requirement that those researchers network with other scholars more directly interested in nanotechnology (by, for example, going to at least one NSF-sponsored conference on social studies of nano during their grant).

Novelty

So why does this matter? It could be that nanotechnology just doesn't need insights from history. Obviously, I think otherwise – so let me supply a few reasons. First, the usual rationale given for *and* against nanotechnology have a strange, probably unhealthy, perspective on the past which historical research can possibly rehabilitate.[13] In particular, both nano's proponents and critics want it both ways in terms of the novelty of the field. For supporters, nano is new, revolutionary, the next big thing, etc. until you start talking about regulation, at which point many scientists say something like "oh, it's just molecules, we've known how to handle those for a hundred years." Critics try to stir up passions about a new, scary, untried technology – but then they also want to hammer on a well-tested rhetoric about wealthy corporations in the West "once again" exploiting the little guy and threatening our environment. Even a sophisticated history of nano could not *adjudicate* these uses of novelty, but (with luck) if such a history entered public discourse it would encourage supporters and critics to be more sophisticated and discriminating about how and when they cast nanotechnology as novel.

[13] I offer a preliminary analysis of this attitude in Mody, Cyrus C.M. (2004) "Small, But Determined: Technological Determinism in Nanoscience" *Hyle* 10:99-128.

Here's my own take on the novelty of nano. On the one hand, it's very difficult to see what, precisely, makes nanotechnology different from what came before. Is it (as is usually claimed) that we now have instruments like the scanning tunneling microscope that can "see" individual atoms and therefore can do lots of new things at the nanoscale?[14] Well, no, we've been able to image atoms since the mid-'50s.[15] Is it all the new interdisciplinary nanocenters being funded, such as the University of Pennsylvania's Nano-Bio Interface Center? Well, there are a lot more such centers today than there were 10 years ago, but some of those institutions have existed since the mid '70s – though often with "micro" instead of "nano" in their original name. Is it all the new conferences and journals dedicated to "nano" topics? Again, there are more now, but some of the most important nano conferences have been around since the mid-'70s, again with the nano-for-micro substitution made at some point. Is what's new the use of "nano" as a buzzword? Well, "nano-technology" was coined in the mid '70s, specifically to mean "the technology that comes after micro-technology". But, more importantly, there is a long, long history of buzzwords to describe "the next smallest technology." My colleague Hyungsub Choi found a wonderful one from the early '60s – "angstronics."

On the other hand, nanotechnology is not – as many historians of science and practicing scientists and engineers believe – merely reheated materials science. There is more to it than hype and relabeling. If only because the declaration of novelty does a lot of real work, especially in a field so dominated by federal planning, there *is* something

[14] Baird, Davis and Ashley Shew (2004) "Probing the History of Scanning Tunneling Microscopy," in *Discovering the Nanoscale*, ed. D. Baird, A. Nordmann, and J. Schummer (Amsterdam: IOS Press): 145-156 nicely lays out this "standard history" of nano.

[15] Mody, Cyrus C.M. (2004) "How Probe Microscopists Became Nanotechnologists," in *Discovering the Nanoscale*, ed. D. Baird, A. Nordmann, and J. Schummer (Amsterdam: IOS Press): 119-133 points out both the extensive use of field ion microscopy in '50s and electron microscopy in the '70s to see atoms. I also show that, contrary to the standard history, probe microscopists were generally uninterested in "nano" until large pots of money induced them to adopt the label after 2000.

new about nano.[16] Here's a thumbnail history of how such declarations matter: the institutions and communities presently under the nano umbrella have their roots in '70s and '80s, when they operated largely independently of each other. In the '90s, though, they began to notice each other, largely through the mediation of federal grant officers.

These grant officers, and elite members of these institutions and communities, needed an organizing principle to describe and justify this process of "noticing" – for which "nanotechnology" was a handy term borrowed from a variety of both scientific and lay sources. This "noticing" and coordination is what's novel, because it allows for certain institutional forms to be replicated across different communities, for new kinds of collaborations between communities, and for materials and information to flow around multiple communities.[17] There is very little new knowledge in nano today – i.e. knowledge that is different from (or would not have been created by) more traditional fields like chemistry, materials science, and electrical engineering. The hope of supporters, though, is that by creating these new *institutions* now, new *forms of knowledge* will emerge down the road.

This points to a second reason for involving historians more fully – definitions. I have yet to go to a policy meeting about nano in which the definitions of "nanotechnology," "nanoparticle," "nanoscience," etc. have not been firmly contested. None of the definitions offered thus far seem to meet even their authors' objectives for including things which are novel while excluding things which are not.[18] Such

[16] McCray, W. Patrick (2005) "Will Small Be Beautiful? Making Policies for Our Nanotech Future" *History and Technology* 21:177-203 details the role of federal planning in calling nanotechnology into being.

[17] For the key work on replication of institutional forms through an organizational field, see DiMaggio, Paul J. and Walter W. Powell (1983) "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields," *American Sociological Review* 48:148-160.

[18] Almost every organization or prominent individual in nano has put forth their own definition. They range from the specific (from the NNI: "nanotechnology is the understanding and control of matter at

definitions matter – if nanotechnology is deemed novel enough to require new funding structures or new regulatory regimes, then we need to know what those policies will apply to. If the definitions only point to novel materials, the public may well wonder why it is not being protected from what appear to be similar risks from older particles; but if the definitions include all "nano" materials, products that have been deemed safe for years will suddenly (and perhaps unnecessarily) need to be re-certified.

For example: there is a class of materials known as "carbon blacks" which have been known and manufactured in large quantities for well over a century.[19] According to the International Carbon Black Association, global production is about 18 billion pounds per year, about 70% of which goes into tires, 20% into everything else made from rubber (hoses, sneakers, gaskets, etc.), and the rest into plastics, inks and toners, radar-evading aerospace materials, and even pencil lead.[20] At one time carbon black was even used as a food coloring in licorice and jelly beans and to surreptitiously dye whitefish eggs to sell as caviar.[21] It's carcinogenic and, like carbon nanotubes, made from virtually pure carbon. It is formed from particles which range from 20 nm to 350 nm depending on method of manufacture, though most methods produce particles well under 100 nm (the NNI limit). Though its use in reinforcing tires is relatively low-tech, it still has high-tech

dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale") to the diffuse (from Richard Smalley: "the art and science of making stuff that does stuff at the nanometer scale"). See http://nano.gov/html/facts/whatIsNano.html and Smalley, Richard (2003) "Nanotechnology, Energy, and People," (Houston: speech at MIT Enterprise Forum): http://smalley.rice.edu/emplibrary/Transcript%20MIT%20Forum%20RES%20edit.doc.

[19] Cerveaux, Augustin (2007) "Hypotheses for the History of Nanotechnology," paper for Joint Wharton-Chemical Heritage Foundation Symposium on Social Studies of Nanotechnology contains some nice insights on the history of engineered nanoparticles from carbon black to the present.

[20] See http://www.carbon-black.org/what_is.html.

[21] Sinclair, Molly (1980) "Debate over Food Safety Launched by Cranberry Scare of '59" *Washington Post*: Nov. 22, C1; Living Desk (1981) "Is it true that some caviars are colored with a black dye?" *New York Times*: Mar. 18, C8.

applications; and at various times it has been a core product of some of the most innovative materials firms – e.g. DuPont, Degussa, Cabot, Huber, and even Binney & Smith (the predecessor company of Crayola).

It is extraordinarily hard to compose an ahistorical definition of nanotechnology that does not encompass carbon black. Yet there is little appetite on anyone's part – supporters, critics, agnostics – to stretch nano policy, funding, or regulatory frameworks to include this material. At a recent NIH workshop on nano-toxicology, for instance, I saw a well-known expert on nano-toxicology (and public perceptions thereof) cornered into admitting that carbon black would have to count as a nanoparticle, but that (since it's been around for so long) we probably know enough about its properties that there's no need to lump it with more modern nanoparticles. This even though, as Patrick McCray discovered when he "recently talked with a materials scientist who works for Michelin":

> We discussed whether or not Michelin is doing nano...he referred to the longstanding usage of nano-size 'carbon black' as a tire reinforcement and noted that it remains an industry mystery where the particles go as they wear away from tires and are deposited all along the world's highways.[22]

Unfortunately for the tidy ambitions of the NSF, historical research can only make definitional problems like that of carbon black worse before they get better. The more we learn about carbon black and other ambiguously-nano materials, the more we're likely to see continuities with today. But, surely, that's all the more reason for the NSF to sponsor historians to look deep into these materials' past. As we'll see in the next section, most nano-ELSI is predicated on an instinctive comparison between nanotech and other "revolutionary" high-tech sectors, especially biotechnology. Given nanoists' tendency toward revolutionary rhetoric it makes sense for historians and sociologists to

[22] McCray, Patrick (2007) "The Particle Police" http://centernanosociety.blogspot.com, January 14.

study the “perpetual revolution” of high-tech.[23] But definitionally-ambiguous entities like carbon black highlight the importance of also surveying nano’s longer history as a Kuhnian “normal” science.

That is, no one pinned hopes of a new industrial revolution on carbon black or described it as “the basis for a true technology revolution in our society” in the way they do with nano.[24] But also no one automatically assumed that at some point carbon black would become controversial (as they do with today’s nano). Even when carbon black was banned as a food additive, no one assumed – as, again, they seem to with today’s nanoparticles – that there would be a domino effect leading to the banning of carbon black in tires, sneakers, pencil lead, bombers, or toner. Considering that companies like DuPont, Degussa, and Cabot are at today’s leading edge in nanomaterials and microelectronics, we have an opportunity for a study of continuous corporate involvement in nanotechnology for over a century. This could tell us a lot: how some nanomaterials in some contexts have become controversial and some haven’t; how and why firms have evolved new uses for manufactured nanoparticles; and how and why firms have done the internal boundary work to distinguish old-line nanomaterials from today’s nano.[25] This *might* in turn provide a definition of nanotechnology that is grounded and specific enough to resist most charges of arbitrariness. It will certainly provide a baseline “normal science” view of nanoparticles to contrast with other ELSI work predicated on a “revolutionary science” view.

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[23] “Perpetual revolution” is a Trotskyite mantra, but I mean it more in the Kuhnian sense of “revolutionary” versus “normal” science. Kuhn, Thomas (1962) *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press).

[24] As did no less a person than the U.S. President’s Science Adviser. See Marburger, John H., III (2007) “The Future of Nanotechnology,” *Nanotechnology: Societal Implications I* (Dordrecht: Springer): 16-21.

[25] Gieryn, Thomas F. (1983) “Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists” *American Sociological Review* 48: 781-795.

Analogies

Unfortunately, even though the NNI is supporting very little historical research, both supporters and critics of nano continually evoke what they take (often dubiously) to be the lessons of history. One explicit reason for the annual $40 million in ELSI funding is so that social scientists and ethicists can help the NNI avoid the "mistakes" of biotechnology – based on the assumption (which one continually hears) that in every other way nano will unfold exactly like biotech.[26] Indeed, the impetus for nano-ELSI is that a similar program "worked" for the last large, federally-funded biotech effort, the Human Genome Project. Similarly, critics' rhetoric often reads as though they had plagiarized their old tracts and simply replaced "bio" with "nano". This automatic use of the analogy to the history of biotech has, unfortunately, been taken up unquestioningly by many people in nano-studies.[27]

Clearly, aspects of that analogy should be taken seriously, particularly since both supporters and critics take biotech as a basis for a nano "game plan" – the analogy is performative and partially self-fulfilling. Yet the scientific fields in which most nanotechnologists were trained – semiconductor physics, electrical engineering, materials science, supramolecular chemistry – have developed very differently from biotech. Most of these fields have not encountered public skepticism in the way biotech has. Where, for instance, is the public backlash against semiconductor physics or the semiconductor industry – even though that industry's environmental and occupational health record, and its practice of off-shoring labor, could easily have provided the grounds for significant

[26] Weiss, Rick (2004) "For Science, Nanotech Poses Big Unknowns" *Washington Post:* Feb. 1, A01 offers some wonderful examples of this.
[27] Sandler, Ronald and W.D. Kay (2006) "The GMO-Nanotech (Dis)Analogy" *Bulletin of Science, Technology, and Society* 26: 57-62 offers some nice challenges to the analogy, but then falls back into the trap at the end.

public resistance.[28] Why, then, should nano-ELSI simply repackage analytical tools developed for understanding biotechnology? Why not look for other analogies? Again, historical research can't offer the "right" historical analogy for nano, but this debate could only improve if we can draw on several analogies, rather than trying to cram everything into the biotech mold – a mold which, as we'll see, is based on a schematic and faulty understanding of the history of biotech. The NSF has a clear interest in funding more and better histories of a variety of fields that, in one respect or another, are analogous to nanotechnology.

For instance, we desperately need a really good history of materials science, one of the fields most closely related, analogically *and* genealogically, to nano.[29] From what little we know, the development of nano closely parallels that of materials science. That field was pushed from above in the late '50s by federal funding agencies, first DARPA then the NSF (agencies which played the same role for nano in the '90s). Simultaneously, it was pushed from the middle by practicing scientists with futurist inclinations, such as Arthur von Hippel (likewise Rick Smalley for nano); and it was originally hauled into being through the creation of federally-funded interdisciplinary academic centers (much like the NSECs of today). The content, organization, and history of materials all presage, and flow into, nanotechnology. A richer historical understanding of materials science would tell us all kinds of things about how a transdisciplinary discipline like nano is constructed both by federal fiat and elite scientific vision. It would

[28] There is a small literature on the semiconductor industry's excesses, mostly from the margins of the academy: Matthews, Glenna (2003) *Silicon Valley, Women, and the California Dream* (Stanford: Stanford University Press); Pitti, Stephen J. (2003) *The Devil in Silicon Valley: Northern California, Race, and Mexican Americans* (Princeton: Princeton University Press); Krantzler, Mel and Patricia Biondi Krantzler (2002) *Down and Out in Silicon Valley: The High Cost of the High-Tech Dream* (Amherst, NY: Prometheus Books).
[29] This section owes a great deal to discussions with Patrick McCray and Jim Murday.

tell us how interdisciplinarity actually develops in specific contexts. And it would show us where skepticism and resistance do and do not appear, both within scientific community and amongst the broader public. And yet, the lessons of materials science are consistently drowned out in social studies of nano by the siren call of biotechnology.

Even if we heed that call, let's give the comparison to biotech some useful texture. For instance, as Arie Rip notes, nano policymakers continually warn that public perceptions of biotechnology rapidly moved along a trajectory from "wow" to "yuck".[30] As Rip further notes, this view is almost wholly fallacious. Well-reasoned critiques of biotech captured public interest more or less coincident with the birth of the field in the '70s; indeed, regulatory regimes set up in response to public "yuck" strongly shaped the early biotech industry.[31] So even if the biotech-nanotech analogy were apt, the assumption of a wow-yuck trajectory would not be. If the NNI is going to use biotech as its game plan, it should be paying for, and then paying attention to, detailed histories of that field, rather than simply assuming that it knows that history and the lessons it offers.

The wow-yuck story offers another important lesson. When you converse with prominent nanoscientists, you often hear their frustration that the public is being "irrational," or that they are led astray by NGOs with an agenda "just like they were with genetically modified foods," that the public doesn't understand that all of biology is built on nanomachines and therefore they should have nothing to fear if only they could be informed, that GMOs "failed" because there wasn't enough education (K-12 and beyond) to get people aware and therefore enthusiastic. As Steven Currall and Neal Lane ask,

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[30] Rip, Arie (2006) "Folk Theories of Nanotechnologists" *Science as Culture* 15: 349-365.

[31] Kenney, Martin (1986) *Biotechnology: The University-Industry Complex* (New Haven: Yale University Press); Hall, Stephen (2002) *Invisible Frontiers: The Race to Synthesize a Human Gene* (New York: Oxford University Press); Bud, Robert (1993) *The Uses of Life: A History of Biotechnology* (Cambridge, UK: Cambridge University Press).

> [W]ill the fate of nanotechnology be determined by rumour and supposition, *as some believe has been the case for GMO*? Or will public opinion be based on objective science and engineering findings?... [I]t is vital that bench researchers who are conducting toxicological analyses of nanotechnology, and others who are studying its potential benefits, redouble their efforts to be thorough, transparent, and timely in disseminating their results. This information will minimize the likelihood that the public develops polarized perceptions of nanotechnology based on rumour and supposition and hence avoid potential overreactions *such as those that occurred with GMO*.[32]

First, it's odd that there's this constant talk about GMOs "failing" – it would be difficult to eat a salad or drink a soda in North America without ingesting some GMOs, and even the countries that protested most are now giving ground. But, second, what do nanoscientists (and even social scientists like Currall) think the GMO controversy was about? Do they really think the whole basis for "irrational" public outcry was the possibility that foreign genes would somehow wreak biological havoc on consumers' bodies? That seems a very thin reading of the debate. Everything written by historians and sociologists of science indicates that while toxicological risks were an important (but not the only) rhetorical battlefield, the triggers for protest had much more to do with what "hidden histories" of biotech – i.e. long-running threads of unease about intellectual property, Western domination of developing countries, independent producers versus big corporations, culturally-important understandings of life and biology, globalization, and, of course, a legacy of government/scientific deceit and manipulation around events the *public* saw, quite reasonably, as analogous (hoof and mouth, mad cow, Bhopal, Chernobyl, etc.).[33]

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[32] Currall, Steven C. *et al.* (2006) "What Drives Public Acceptance of Nanotechnology?" *Nature Nanotechnology* 1: 153-155. My emphasis.

[33] Lezaun, Javier (2006) "Creating a New Object of Government: Making Genetically Modified Organisms Traceable" *Social Studies of Science* 36: 499-531; Delborne, Jason (2005) "Pathways of Scientific Dissent in Agricultural Biotechnology" (Berkeley, Cal.: University of California Ph.D. dissertation). The "hidden histories" concept is indebted to conversations with Patrick McCray and Mary Ingram-Waters

I.e., seeing the GMO controversy as "about" toxicological risk is like seeing the Iraq war as "about" weapons of mass destruction – it's one factor among others, even if (for a time) it dominates the debate. And yet, as the Currall and Lane quote amply shows, the nano policy debate right now is dominated by a fear that nano will fall prey to "the same" toxicological worries. Policymakers are therefore consumed by an entirely instrumental obsession with toxicological risk – as though the right toxicological studies will, on their own, dissolve any problems with public perception. Here is a place where historians and social scientists have a duty to come forward and vigorously assert the importance of "hidden histories" in past controversies. Perhaps I make the same mistake as nanoscientists in hoping that "the facts" will magically change entrenched opinions, but I do believe that if nanoscientists can accept that historians and qualitative sociologists have an empirically valid body of expertise then they would have a much better understanding of how technical controversies play out in public.

Hidden Histories

Once that step has happened, we can move on to more prospective studies. We don't have to wait for some assumed nano controversy to start thinking about what hidden histories would be relevant. Some of those hidden histories will be similar to those for GMOs, but with a nano twist – what, for instance, are the important culturally-inherited valences of rubbing a controversial inorganic particle on your skin (e.g. to protect you from sunburn) as opposed to the inherited understandings of ingesting a controversial organic particle as food? Other hidden histories will be more nano-specific. We are already starting to see some interesting work on the long-standing cultural threads of privacy and threat awareness that will interact with perceptions of nano-sensors.[34] But

[34] Toumey, Chris (2007) "Plenty of Eyes at the Bottom," *Nature Nanotechnology* 2: 192-3.

there are plenty of so-far-overlooked hidden histories. What, for instance, are the culturally-important symbols and resonances of *computing* that will interact with nanoelectronics applications? This is an area science studies has plumbed relatively well, and the NNI should be more proactive in drawing on the expertise of historians and ethnographers of computing such as Paul Edwards and Mimi Ito.[35]

Above all, what long memory of risk or benefit will the public associate with the places where nano will be used (e.g. hospitals, waste treatment facilities, battlefields, etc.) and the companies that will sell nano-products (e.g. DuPont, IBM, Hewlett-Packard)? Currall and Lane might find it "irrational" to mistrust DuPont's claims about the safety of its nanomaterials, but probably the residents of towns in West Virginia that were contaminated with a chemical, PFOA, about which DuPont hid known health risks for 25 years, will think otherwise.[36] Doing the toxicological research is important; being transparent about the results is even better; but there are still going to be elements of the public that have good reasons, inherited from past experience, not to trust those results. Calling these people "irrational" will only dig a deeper hole; but tracing out the history that molds their attitudes can show how they are at least as rational as the nano faithful. From there, a debate can take shape that actually addresses underlying concerns, instead of just rallying around the surface layer of toxicological worries.

My sense is that the hidden history that will matter most is the one the NNI has tried hardest to stifle – namely, the cultural valences of nano inherited from science

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[35] Edwards, Paul N. (1996) *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass.: MIT Press); Ito, M. (2005) "Mobilizing Fun in the Production and Consumption of Children's Software," *Annals of the American Academy of Political and Social Science* 597: 82-102.

[36] Eilperin, Juliet (2005) "DuPont, EPA Settle Chemical Complaint: Firm Didn't Report Risks, Agency Says" *Washington Post* Dec. 15, D3.

fiction and futurism.[37] These voices dominated publicly available notions of nanotechnology for a good 15 years prior to the NNI, through novels by people like Greg Bear, Arthur C. Clarke, and Kathleen Ann Goonan and – probably more importantly – television shows such as *Star Trek*, *X-Files*, and *Stargate*, and movies such as *Spiderman*.[38] It is hard to imagine that doesn't leave a residue on public perception. Indeed, when I mention to laypeople (including practitioners of non-nano sciences) that I study nanotechnology, about half of them immediately mention "tiny robots." That's not a vision of nano that gets any encouragement from official industry or government pronouncements or even from the popular press. It is, however, exactly the version of nanotechnology deployed in *Star Trek* and the *X-Files*.

As Patrick McCray has remarked, nano could easily go the same way as the space race, which wound to a close partly because of public disinterest once the real moon landings paled in comparison to the optimistic can-do of *Star Trek* and the boundless imagination of *2001*.[39] "Tiny robots" are an imaginatively compelling narrative, likely to dominate the nano stage for some time. Fortunately, we are beginning to see some ELSI work analyzing the nanobots and their ramifications.[40] Unfortunately, many of these

[37] I should note that my collaborators at the UCSB CNS, Patrick McCray and Mary Ingram, are working in this area and producing wonderful, informative, occasionally humorous findings.

[38] An aside: Arthur C. Clarke may seem an odd inclusion here, since he rarely makes other lists of nano SF writers. I have in mind his space elevator novel, *Fountains of Paradise* (1979). Since the space elevator is one of the most-touted and most imaginative applications of carbon nanotubes, I suspect Clarke's book (and other science fiction inspired by it) will be at least as influential on public attitudes as novels that are explicitly about nano. This is a common feature of the ahistorical nature of nano-ELSI – by only concentrating on the *explicitly* nano, we ignore the big picture of ideas and institutions that *indirectly* influence nano.

[39] Personal communication. Another instance where at least one aspect of nano would benefit from richer histories of (and analogies to) a field other than biotechnology.

[40] E.g., Milburn, Colin (2002) "Nanotechnology in the Age of Posthuman Engineering" *Configurations* 10: 262-295; Landon, Brooks (2004) "Less is More: Much Less is Much More: The Insistent Allure of Nanotechnology Narratives in Science Fiction," in *Nanoculture: Implications of New Technoscience*, ed. N. Katharine Hayles (Bristol: Intellect Books); Berne, Rosalyn W. (2006) *Nanotalk: Conversations with Scientists and Engineers about Ethics, Meaning, and Belief in the Development of Nanotechnology* (Mahwah, NJ: Lawrence Erlbaum).

authors take a fairly ahistorical perspective on the texts they examine. We know a great deal now about, for example, what Eric Drexler and Richard Feynman said in public about tiny robots. Yet we know next to nothing about why they said those things, how their pronouncements fit into a complex of prior and subsequent texts, or why we should emphasize those two men's contributions to nano more than others.

Critically, we could stand to learn much more about the networks surrounding early nano-enthusiasts, particularly the community of Bay Area techno-libertarian futurists who were influential in other high-tech arenas.[41] We know that Drexler's ideas got an early hearing from a fairly diverse and influential group: Al Gore, Adm. David Jeremiah, Neal Stephenson, Federico Capasso, etc. But we don't have the historical context to see how Drexler accrued the credibility and the contacts to secure that hearing. Nor do we know what ongoing ideologies of science and technology within the military-industrial-academic-entertainment complex his molecular assemblers piggy-backed onto.[42] Nor can we yet tell how his ideas circulated within that complex and transmuted into the "tiny robots" that many people automatically associate with nanotechnology. Instead of simply bewailing the prevalence of nanobots, perhaps the NNI should sponsor fine-grained historical and sociological research to discover just how the nanobots became so compelling. This could offer nanoists (as well as their critics) useful insights in how to craft an alternative, equally compelling nano-narrative and move it toward the

[41] Turner, Fred (2006) *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago: University of Chicago Press); Brooks, Lonny (2004) "Working in the Future Tense: Managing Stories of Emerging Technologies and Cyberculture at the Institute for the Future" (San Diego: UC San Diego dissertation). Regis, Ed (1995) *Nano: The Emerging Science of Nanotechnology* (Boston: Little, Brown) contains some wonderful material that could be the starting point for such a study.

[42] I don't mean to reify such a complex – rather, it is a shorthand for the interlocking networks affiliating different spheres of activity that influence public opinion.

mainstream. It could also (as I'll discuss below) offer a way to deal with Drexler's legacy which is neither credulous nor dismissive.

An Example: Molecular Electronics

There's a second kind of hidden history that could be useful, one tuned more to helping policymakers understand just how their actions will ramify through the infrastructure of nano. These would be histories of the organizational fields that intersect with or exert pressure on the organizational field of nanotech. This is my own area of specialization, so an example is in order. Hyungsub Choi and I have written a history of molecular electronics that perhaps demonstrates how history could be useful to policy. Hyungsub is an historian of microelectronics; in the course of his dissertation he uncovered a program at Westinghouse in the late '50s and early '60s on "molecular electronics." In my work I had run across a field of the same name that gained strength in the late '80s and '90s as one of the leading areas of nanotechnology. Were they connected? Certainly, virtually none of today's molecular electronics researchers have heard of the Westinghouse program; but, as I've emphasized here, nanoists have an unusual and incomplete relation to their own history. We decided to take a closer look and see what "molecular electronics" has meant these past 50 years.[43]

Let me emphasize that the conclusions we reached could not have been developed without a long-term collaboration between someone working on "nano" and someone working on a topic wholly dissociated from the "nano" prefix. Molecular electronics today houses some of the leading researchers and institutions of the nano community; but you simply cannot understand this critical sector of nanotechnology if you do not look at

[43] Choi, Hyungsub and Cyrus C.M. Mody (forthcoming) "Molecular Electronics in the *Longue Durée*: The Microelectronics Origins of Nanotechnology" *Social Studies of Science*.

its existence apart from nano. This is an endemic problem of social studies of nanotechnology. Researchers have been pulled into nano-studies suddenly because of the appearance of funding (rather than more organically through intrinsic interest) and, in general, they have not been drafted from the disciplines of science studies. This has meant that nano-ELSI tends to focus at a very high level on ideas or organizations that encompass *all of and only* the overtly "nanotechnological." Most nano-ELSI does not examine the content and organization of the *sub*communities of nano; and virtually no nano-ELSI looks at those subcommunities before they started wearing the "nano" label.

What we found undermines that approach. "Molecular electronics" closely resembles Wittgenstein's description of a string – there is no one thread running all the way through the string of molecular electronics, but there are many partially overlapping threads, each bearing some family resemblance.[44] Molecular electronics began as a collaboration between Westinghouse and the US Air Force; after a decade in hibernation, it awoke in a different guise in the mid '70s – first at IBM and then at the Naval Research Laboratory. At NRL, an old Westinghouse alumnus, Forrest Carter, spun fantastic visions for the idea that attracted a nucleus of devotees, yet which proved impossible for his managers to supervise. Thus, for the field to survive into the '90s, the molecular electricians had to come up with a less radical, more dispersed vision of research that would be palatable to a new generation of institutional patrons (DARPA, IBM, Hewlett-Packard).

Some observations on what we found. First, visionaries and futurists – many of them practicing scientists – played a crucial role in creating sustainable interest in

[44] Wittgenstein, Ludwig (1953) *Philosophical Investigations*, trans. G.E.M. Anscombe (Oxford: Blackwell): 32.

molecular electronics. From Arthur von Hippel to Forrest Carter to Jim Tour, molecular electronics has always had some inspiring, charismatic spokesperson. Sometimes, these people come to be seen as having oversold their vision or done "bad science." Indeed, in the broader world of nanotechnology the NNI seems to be doing everything it can to expel this kind of person from mainstream nano. We call for a more balanced approach; these people are critical for cultivating a network of potentially interested researchers and for capturing the attention of patron institutions (firms, funding agencies, professional societies, government labs, etc.). Yet these people can also create difficulties for those same institutions – their vision is usually beyond the horizon of planning, such that they offer little guidance on how bureaucracies should manage researchers from day to day to achieve that vision.

Second, we found interesting ways to understand how "hidden histories" have molded both the vision and the organization of this field. The first iteration of molecular electronics was closely tied to Cold War ideology and strategy. Von Hippel's futurism banked on Cold War desperation for a kind of high-tech manufacturing that would supercede Soviet factory capacity. The management of the Westinghouse project adhered to a "pipeline" model of high-tech development that, as Phil Mirowski and Esther-Mirjam Sent have shown, derived from Cold War ideology and tax structure.[45] The second, 1970s iteration of molecular electronics played on fears of Japanese recrudescence and American decline. The management of molecular electronics efforts over the next decade benefited from the then-popular M-form multidivisional business model that viewed corporate research as its own, distinct product line.

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[45] Mirowski, Philip and Esther-Mirjam Sent (forthcoming) "The Commercialization of Science and the Response of STS" in *Handbook of Science and Technology Studies*, ed. E.J. Hackett, O. Amsterdamska, M. Lynch, J. Wajcman (Cambridge, Mass.: MIT Press).

Finally, the molecular electronics of the '90s through today is a product of the demise of the M-form and pipeline models, and the consequent combination of corporations outsourcing basic research to universities and requiring their own researchers to work more closely with the production line. *And*, while today's molecular electronics extends the early '80s concern with Asian competitors and fascination with artificial intelligence, it also taps into current cultural preoccupations with biology – especially with mind-machine interfaces and even intelligent design (of which Jim Tour is a vocal supporter).[46] We think, then, that our historical approach has shown some of the wider cultural and symbolic valences into which molecular electronics taps – and therefore offers some tools for preparing for public reaction to commercial molecular electronic devices.

The more central point of our study, though, is to illuminate some of the organizational dynamics that have given rise to multiple iterations of molecular electronics over the years. We argue that, since the early '60s, the microelectronics industry has steadily routinized around an interlocking complex of technologies – silicon, integrated circuitry, photolithography. Improvements to that complex are measured in the terms laid out by Moore's Law – steady decrease in critical size and cost per transistor, steady increase in yield and number of transistors manufactured.[47] Since even before Moore's Law was articulated, though, organizations at the periphery of this complex have championed a radical overthrow of the complex – a shift to some post-

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[46] Chang, Kenneth (2006) "Few Biologists But Many Evangelicals Sign Anti-Evolution Petition" *New York Times* Feb. 21, F2.

[47] We have some nice research now on the evolution of Moore's Law: Ceruzzi, Paul E. (1998) *A History of Modern Computing* (Cambridge, Mass.: MIT Press); Brock, David C. (ed) (2006) *Understanding Moore's Law: Four Decades of Innovation* (Philadelphia: Chemical Heritage Foundation); Mollick, Ethan (2006) "Establishing Moore's Law" *IEEE Annals of the History of Computing* 28: 62-75. Unfortunately, this literature, and Moore's Law generally, gets little attention in the nano-ELSI community.

silicon electronics. As the work needed to extend Moore's Law has become ever more expensive and tied together ever more organizations, the prospect of a post-silicon electronics has steadily become both more desirable and less likely.

Thus, visionary post-silicon proposals have continually emerged since the '50s, each time capturing some organization's attention, only to be sidelined. Silicon has many organizations in its thrall and therefore can progress quickly and steadily, whereas alternatives have much weaker institutional support and therefore make sporadic progress. This sporadic progress is then a self-fulfilling reason why more organizations do not abandon silicon in favor of any given alternative. In general, therefore, organizations that initially foster such post-silicon alternatives eventually spin them out into university-based research fields. This happened with molecular electronics in the '70s and '80s as well as to other alternatives such as Josephson computing, quantum computing, spintronics, and so on.[48] When the NNI and other national nanotechnology efforts were forged in the '90s, they were dominated by communities that spun off from microelectronics in this way *or* were eager to have their own shot at a post-silicon future (e.g. the carbon nanotube community).

The organizational dynamics of the microelectronics industry have, therefore, substantially influenced the shape of nanotechnology. And yet, you'd hardly know that from reading the ELSI literature on nano. We believe our exploration of the role of the microelectronics field could be illuminating for policymakers. After all, today's nanoelectronics has arisen in response to a dynamic that has triggered similar responses over the years; understanding that stimulus and the fate of successive responses *could*

[48] Our work on molecular electronics tails well with Patrick McCray's analysis of spintronics: McCray, W. Patrick (unpublished) "Following the Silicon Chip Road: Spintronics, Novelty, and Over-the-Horizon Technologies."

help policymakers shape today's nanoelectronics. Moreover, we believe we have shown a novel, historically-based justification for lumping much of nano together – many of nano's communities share a heritage of having arisen at the organizational periphery of microelectronics. This common lineage *could* be useful in alleviating some of the definitional tensions that I outlined earlier.

Clumpiness

Let me end with one final way that history can matter for nano. Nano is – more or less by definition – "clumpy."[49] The field is composed of all sorts of different communities that have gradually taken notice of each other, but haven't really harmonized their practices, values, career arcs, etc. Some of these constituent communities are affiliated with (sub)disciplines such as surface science or supramolecular chemistry; some with institutions such as a campus microfabrication facility; some with an instrument, such as the atomic force microscope; some with a material, such as the carbon nanotube; some with a philosophy, such as the techno-libertarian futurist community; some with a technoscientific/commercial objective, such as molecular electronics. Both nano's supporters and critics alike – and hence also most nano-studies practitioners – don't usually differentiate these clumps. After all, it is easier to plan for, promote, and criticize a single entity than a variegated mass. Yet good policies and good democratic decisions about nano should take account of these differences.

One requirement for such policies and decisions is good history and sociology that ranges across multiple nano communities. Again, this is where my own work is

[49] By "clumpy" I mean that it is made up of various "epistemic cultures" which can be distinguished from each other in the way detailed by Karin Knorr-Cetina (op. cit. note 1).

trending so I have a certain investment in seeing more research of this sort. But I think there are clear lessons to be drawn here. One area where nano's clumpiness most begs new policies is academic commercialization.[50] I'm currently looking closely at the history of three nano communities: microfabrication, molecular electronics, and probe microscopy. What I've seen is that the role academic entrepreneurialism plays in nanotechnology is so community-specific as to vex any overarching policy. In microfabrication and probe microscopy, for instance, the community's organization fostered practices amongst academics that evolved organically into commercialization – i.e., academics were keen, for structural reasons, to promote pseudo-markets for their work amongst fellow academics; over time pseudo-markets became the real thing. Because these communities were dominated by user-innovators, commercialization happened through small start-ups rather than large firms – though when innovation slowed bigger firms came to dominate.[51] Offering these academics external incentives to commercialize might actually have discouraged the free sharing of knowledge underlying these pseudo-markets, thereby *hindering* commercialization.[52] The more beneficial policy was not to incentivize commercialization, but to remove hindrances to it when it happened organically.

The two fields differed, though, in that an important element of tech transfer in probe microscopy was the mistrust between start-ups and academics generated by the

[50] This section owes a great deal to discussions with Sonali Shah, Patrick McCray, and the Amherst Law and Science Seminar.
[51] This confirms the pattern theorized in Baldwin, Carliss, Christoph Hienerth and Eric von Hippel (unpublished) "How User Innovations Become Commercial Products: A Theoretical Investigation and Case Study."
[52] Shah, Sonali K., Rajshree Agarwal, and David Audretsch (2006) "The Knowledge Context and the Entrepreneurial Process: Academic, User, & Employee Entrepreneurship" (Bloomington: University of Illinois Working Paper #06-0118) gives some nice examples of how the "best" intellectual property regime is highly dependent on the organization of the community to which it applies.

lack of a commercialization tradition; whereas in microfabrication most academics had some prior corporate experience which helped them realize when commercialization was feasible. In the molecular electronics field, meanwhile, commercialization could only happen through firms large enough to compete in the microelectronics industry. Academic start-ups, when attempted, have been lackluster. History shows that the wisest policy here would've been to disincentivize academic start-ups, but to do everything possible to encourage *partnerships* between academic lab groups and corporate patrons.

A focus on clumpiness could also aid in addressing policymakers' concerns about public perception of nano. If we return to the tired biotech analogy, the stark lesson from that field is that public worries migrate from topic to topic within a high-tech domain. In the '70s worries were most acute about recombinant DNA and the unleashing of super-bacteria; in the '90s it was genetically modified organisms and the possibility that sinister corporations were bankrupting Third World farmers and poisoning us with untested food; since 2000, cloning and stem cell research seem to have topped the agenda. Surely nanotech, which is even more heterogeneous than biotech, is open to such an anxiety migration? If so, historical and sociological research that illuminates the social organization of nano may well help both critics and supporters in focusing debates to specific areas. After all, supporters will want debate limited to as small an area as possible; while critics may want to be able to demonstrate that they are not mere refuseniks, that they support "progress" in some areas of nano while raising concerns about other areas. Historical research can show how different parts of nano are connected and in what ways variation between nano's subcommunities is significant enough to affect policy.

Conclusion

This paper is an apologia for nano-history. My aim has not been to detract from other approaches to social studies of nano, but to show what's been missing (and why). I hope I've demonstrated that there are several big nano-ELSI topics that beg better historical context. As Marx put it:

> Men make their own history, but they do not make it as they please; they do not make it under circumstances of their own choosing, but under circumstances existing already, given and transmitted from the past. The tradition of all dead generations weighs like an nightmare on the brains of the living. And just as they seem to be occupied with revolutionising themselves and things, creating something that did not exist before, precisely in such epochs of revolutionary crisis they anxiously conjure up the spirits of the past to their service, borrowing from them names, battle slogans, and costumes in order to present this new scene in world history in time-honoured disguise and borrowed language.[53]

Nanoists are building a nano revolution, but they borrow the materials of the past to make it. Like any good builder, they should know the quality of those materials, how they are constituted, what they are worth, and whether they will bear the weight put on them.

[53] Marx, Karl (1978) "The Eighteenth Brumaire of Louis Napoleon" in *The Marx-Engels Reader*, ed. R.C. Tucker (New York: Norton): 594-617.