# Not *That* Much Room? Nanotechnology, Networks and the Politics of Dancing

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## I. At the Bottom

> 'There's plenty of room at the bottom.' But there's not *that* much room.[1]

In his well known 2001 article in *Scientific American*, Nobel chemist Richard Smalley offered the above rejoinder to the late Nobel physicist Richard Feynman and to the molecular nanotechnologists that Feynman inspired over the last several decades.[2] Smalley's agenda in that short article was brutally clear. His aim was to draw a laser bright distinction between two very different conceptions of nanotechnology. Smalley made it painfully obvious that not all nanotechnologists aim to create *nanobots* — the autonomous self-replicating molecular assemblers that have been receiving so much bad press since the bong of the new millennium.[3] In fact, Smalley tried to demonstrate that the actual construction of such devices is impossible.

In order to fully appreciate the significance of Smalley's rejoinder, it is first necessary to get to the bottom of Feynman's original vision, which he articulated in his famous 1959 address to the American Physical Society titled, "There's Plenty of Room at the Bottom."[4]

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[1] Richard Smalley, "Of Chemistry, Love and Nanobots" (2001) 285 Scientific American 76 at 77.

[2] In particular, K. Eric Drexler.

[3] See *e.g.* Bill Joy, "Why The Future Doesn't Need Us" *Wired* 8.04 (April 2000), online: Wired <http://www.wired.com/wired/archive/8.04/joy.html>; Michael Crichton, *Prey* (New York: HarperCollins 2002).

[4] Richard Feynman, "There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics." (Lecture given to the American Physical Society, California Institute of Technology, December 29, 1959) (1960), Engineering and Science 23 at page 22-36, reprinted in *Miniaturization*, Horace Gilbert, ed, (New York: Reinhold, 1961), online: Zyvex <http://www.zyvex.com/nanotech/feynman.html> [*Feynman*].

On that memorable December day,[5] Feynman dreamed about a new field of physics — one that "seems to be bottomless and in which one can go down and down."[6] In his usual clever style, he offered a number of compelling examples to illustrate that "there is plenty of room" to descend. So much room, thought Feynman, that "in the great future" it might be possible to "arrange the atoms the way we want … all the way down."[7] And so Feynman invited his audience of fellow scientists to help create this new field of experimental science by asking them to ponder the following question:

> *What would happen if we could arrange the atoms one by one the way we want them*?[8]

Feynman challenged the scientific community by asking this question, inspiring them to think big by thinking small. Recognizing the need to take incremental steps, he announced his intention to offer a reward of $1000 to the first person who could take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale, so that it would be readable by an electron microscope.[9]

He also imagined other contests:

> They could have competition in high schools. The Los Angeles high school could send a pin to the Venice high school on which it says, 'How's this?' They get the pin back, and in the dot of the 'I' it says, 'Not so hot.'[10]

Small steps. But the big picture beneath it all was premised on a hunch that Feynman had about the natural sciences:

> The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. [I]t would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that a chemist writes down. How? Put the atoms down where the chemist says, and so you make the substance.[11]

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[5] The day was memorable in an unusual sense. Like the field of nanotechnology itself, neither of the authors of this paper were yet born.

[6] Feynman, *supra* note 4 at para. 1. This new field, which would later be seen to include other branches of science, including the applied sciences, has since become known as *nanotechnology*.

[7] *Ibid.* at para. 53.

[8] *Ibid.* (emphasis added).

[9] *Ibid.* at para. 67. More recently, in 1996, Carl Feynman, MIT-trained computer scientist and son of Richard, authorized and participated in defining the conditions of a much more substantial prize offered by the Foresight Institute the $250,000 Feynman Grand Prize in Nanotechnology which requires building a 100-nm scale robotic arm demonstrating the controlled motions needed to manipulate and assemble individual atoms or molecules into larger structures, with atomic precision.

[10] *Ibid.* at para. 66.

[11] *Ibid.* at para. 64.

It is the feasibility of this hunch — not to mention the grand and powerful agenda that it might support — that is hotly contested today by Smalley and others.[12]

Before further considering the current debate amongst contemporary nanotechnologists and its potential regulatory implications, it is perhaps worth mentioning that, even in 1959, Feynman recognized that mere intellectual curiosity about his hunch would soon give way to economic incentives. He did not expect that "such prizes will have to wait very long for claimants."[13] And he was right about that. What he likely could not have imagined in 1959 was the magnitude of future incentives in the field.[14] Standing in the midst of Caltech — the very campus where Feynman cultivated his vision — President Clinton ushered in the new millennium by announcing: "My budget supports a major new National Nanotechnology Initiative (NNI), worth $500 million."[15] Less that one full presidential term later, the *21st Century Nanotechnology Research and Development Act*[16] passed through the U.S. Congress and is awaiting the signature of President Bush. Among other things, this *Act* authorizes $3.7 billion for research and development programs coordinated among several federal agencies.[17] Some private sector participants are projecting that nanotechnology will generate a $ 1 trillion industry by 2015.[18]

In addition to its potential for seriously big business, another thing that Feynman did not foresee on that winter day in 1959 — something not terribly unusual for a scientist living on the edge of a dream — was that the fulfillment of his vision would by necessity carry with it tremendous ethical and social implications.[19]

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[12] The most popular version of this heated debate involves exchanges between Richard Smalley and the most famous adherent to Feynman's vision, K. Eric Drexler. The most popular debate is between K. Eric Drexler and Richard Smalley. See: Rudy Baum, "Nanotechnology: Drexler and Smalley make the case for and against 'molecular assemblers'" *Chemical &Engineering News* 81:48 (1 December 2003) 37, online: C&EN <http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html>. Elements of this debate are further considered below in Part III.

[13] Feynman, *supra* note 4 at para. 69.

[14] After all, it is not implausible to project that the future stakes in this industry could one day relegate Feynman's original $1000 economic incentive, relatively speaking, to the nanoscale.

[15] William Jefferson Clinton, Clinton To Caltech on Science and Technology (21 January 2000), online: Office of Strategic Initiatives Columbia University
<http://pr.caltech.edu/events/presidential_speech/pspeechtxt.html>

[16] Pub. L. 108-153, § 189 (2003), online: Thomas
<http://thomas.loc.gov/cgi-bin/bdquery/z?d108:SN00189:@@@L&summ2=m&>

[17] See Tom Krazit, "US nanotechnology funding called for" *IDG News Service* (8 March 2004), online: Industry Standard <http://www.thestandard.com/article.php?story=20040308221444950>.

[18] Mihail Roco & William Sims Bainbridge, eds., *Societal Implications of Nanoscience and Nanotechnology*, (Boston: Kluwer Academic Publishers, 2001) at 3-4, online: World Technology Evaluation Center <http://www.wtec.org/loyola/nano/NSET.Societal.Implications>.

[19] Feynman is not the only one to have neglected the ethical implications of nanotechnology. Recent research indicates that, despite its potential impact and the abundance of available funds, "there is a paucity of serious, published research into the ethical, legal, and social implications of [nanotechnology]. As the science leaps ahead, the ethics lags behind." Anisa Mnyusiwalla, Abdallah-Daar & Peter Singer, "'Mind the Gap': Science and Ethics in Nanotechnology" (2003) 14 Nanotechnology at R9, online: California Council on Science & Technology <http://www.utoronto.ca/jcb/pdf/nanotechnology.pdf>

For example, Feynman did not express any concerns to his audience on that day about the potential economic disruptions and the corresponding social implications sure to accompany the abundantly cheap products that might be mass produced by those who become capable of 'putting the atoms wherever the chemist says.' Neither did Feynman turn his mind to other possibilities that seem immediately obvious these days, for example, the risk to society at large if certain powerful applications of nanotechnology caused severe environmental damage, generated an unstable arms race or, perhaps worse, if they were somehow to fall into rogue hands.[20] Feynman had not contemplated any of the dreadful sci-fi scenarios popularized by Bill Joy, Michael Crichton and others, such as the possibility of free range self-replication or other possible forms of environmental catastrophe.[21] Nor did he ponder the social and ethical implications of nanomedicine, or the possible advances that applications of nanotechnology might yield in the other fields including cryo-biology and life extension.[22]

The history of science is perhaps replete with examples of similar intellectual omissions in the wake of discovery.[23] And history itself has been relatively forgiving of those scientists who have made them, often with good reason.

The aim of this article is not to focus on those omissions, nor to criticize Feynman or others for not having turned their minds to them. Other articles in the literature are sure to address the paucity of ethical discourse in this burgeoning field. Our very narrow aim is to focus on two broad responses to Feynman's vision, both of which have been adopted by key figures interested in the science and ethics of nanotechnology. By considering these two responses and the debate that they have generated, we hope to illustrate how scientific discourses about future technologies can influence regulatory policy.

In examining the discordant influence that the current debate can have on policy-making, we suggest that the traditional point/counter-point approach to

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["Mind the Gap"]; Etc. Group, "The Big Down: Atomtech: Technologies Converging At The Nano-Scale" (2003), online: Etc. Group <http://www.etcgroup.org/documents/TheBigDown.pdf>.

20 K. Eric Drexler, *Engines of Creation: The Coming Era of Nanotechnology* (Garden City: Anchor Press/DoubleDay, 1986); Mark Avrum Gubrud, "Nanotechnology and International Security" (Paper presented to the Fifth Foresight Institute Conference on Molecular Nanotechnology, November 1997), online: Foresight Institute <http://www.foresight.org/Conferences/MNT05/Papers/Gubrud/>; Center for Responsible Nanotechnology, "Dangers of Molecular Manufacturing", online: CRNO <http://crnano.org/dangers.htm>.

21 Sometimes known as the *gray goo* problem, see Ed Regis, *Nano the emerging science of nanotechnology: remaking the world — molecule by molecule* (Boston: Little, Brown, 1995) at 121-124.

22 Robert Freitus Jr., *Nanomedicine, Volume I: Basic Capabilities* (Georgetown, Texas: Landes Bioscience, 1999); *Nanomedicine*, Volume IIA: Biocompatability (Georgetown: Landes Bioscience, 2003); See generally, "Nanomedicine by Rober Freitus Jr.", online: Foresight Institute <http://www.foresight.org/Nanomedicine/>.

23 DDT was discovered in 1873, but its use as a powerful insecticide was not discovered until 1939. It was not until the late 1940s, years after its widespread use that health concerns arose. DDT metabolizes slowly in the body and toxins can build up and remain in the bodies of mammals. DDT was banned in the United States in 1973. *DDT a Banned Insecticide*, online: <http://extoxnet.orst.edu/pips/ddt.htm>.

scientific dialogue does not provide an adequate basis for building normative or regulatory structures. We conclude by raising the possibility that there might be better mechanisms for assessing future technologies and the best means of regulating them.[24]

## II. Nano's Nomenclature

Although perhaps not yet even in its infancy, it is has already been said many times that the development of a powerful and general nanotechnology will transform the world as we know it.[25] Its many promises are thought to include the ability "to drastically reduce energy consumption, to dramatically advance medicine's ability to cure and prevent diseases, and to significantly increase the precision and effectiveness of military devices and weapons."[26] These, in addition to the potential perils mentioned above, are thought to present untold future challenges to scientists, policy-makers, and anyone concerned with the social, economic, ethical, and legal implications of this so-called revolutionary turn in science. How ought today's policy-makers to address such concerns about a technology "so new that, in truth, it barely exists"?[27]

In order to determine whether or when regulation would be appropriate, we first need to determine precisely what it is that we would or would not be regulating.

### What is Nanotechnology?

The term these days is used to refer to a broad range of science and technology working at a length scale of approximately 1 to 100 nanometers. That said, clear consensus on its definition has thus far been elusive. According to Drexler, the scientist said to have coined the term in the mid 1980's:[28]

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[24] This paper does not recommend a specific regulatory method for nanotechnology. There is little doubt that nanotechnology will eventually require some type of government regulation, however, we believe that it is too early to speculate what form such regulation ought to take. At this stage, before a particular policy initiative can be implemented, there is a need to identify potential social, economic, ethical, and policy implications that may accompany the realization of nanotechnology and assess their potential future impact. With Lockean modesty, this paper aims merely to clear the ground for such efforts.

[25] This is even true in the law and policy literature on the subject. See, e.g., Glenn Harlan Reynolds, "Forward to the Future: Nanotechnology and Regulatory Policy" (2002) *Pacific Research Institute*, online: Pacific Research Institute <http://www.pacificresearch.org/pub/sab/techno/forward_to_nanotech.pdf> at 1 ("Nanotechnology…promises to revolutionize many aspects of human society."); Frederick Fiedler & Glenn Harlan Reynolds, "Legal Problems of Nanotechnology: An Overview" (1994) 3 S. Cal. Interdis. L.J. 593 at 594 ("…if nanotechnology does in fact find general application, the impact of on our society is likely to be at least as great as that of the Industrial Revolution.") [*Reynolds*]; Paul Lin-Easton, "It's Time for Environmentalists to Think Small — Real Small: A Call for the Involvement of Environmental Lawyers in Developing Precautionary Policies for Molecular Nanotechnology" (2001) 14 Ga. J. Int'l & Comp. L. 107 at 107 ("Molecular Nanotechnology…promises to be the next revolution.").

[26] Reynolds, *ibid.* at 2.

[27] Reynolds, *ibid.* at 2.

[28] In his landmark book, *Engines of Creation*, *supra* note 20, Drexler has written numerous other books

> The problem started with the word. In labeling the Feynman vision *nanotechnology*, the author chose a word with roots that let it fit any nanoscale technology, no matter how old or mundane.[29]

Because both root words are broad, there is a risk that proposed regulatory mechanisms could be over- or under-inclusive. Consider the following example. Some have called for a relinquishment of nanotechnology, based on the potential dangers that would accompany the development of autonomous self-replicating molecular assemblers.[30] If some form of prohibition were to be enacted today to protect against this future possibility — though it is certainly difficult to imagine a full scale relinquishment of the sort that Bill Joy and others have proposed — it is possible that a number of utterly benign and perhaps socially valuable nanoscale techniques might be banned simply by virtue of the fact that the field has not yet adequately defined itself.[31]

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and articles on the nanotechnology including: K.Eric Drexler, "Building Molecular Machine Systems" (1999) 17 *Trends in Biotechnology* 5; *Molecular Manufacturing: A Future Technology for Cleaner Production. Clean Production: Environmental and Economic Perspectives* (New York: Springer, 1996); "Molecular Manufacturing: Perspectives on the Ultimate Limits of Fabrication" (1995) 353 *Phil. Trans. R. Soc. London A* 323; *Molecular manufacturing: perspectives on the ultimate limits of fabrication. Ultimate Limits of Fabrication and Measurement* (Dordrecht: Kluwer, Academic Publishers, 1995); "Molecular Machines: Physical Principles and Implementation Strategies" (1994) 23 *Annual Review of Biophysics and Biomolecular Structure* 337; "Molecular Manufacturing: A Sustainable basis for Global Wealth" (Fall 1993) *Leaders*; "Towards Molecular Manufacturing. The World in 1992" (1992) *Economist Publications*; "Molecular Directions in Nanotechnology" (1992) 2 *Nanotechnology* 113; "Molecular Manufacturing for Space Systems: An Overview" (1992) 45 *JBIS* 401; *Nanosystems: Molecular Machinery, Manufacturing and Computation* (London: Wiley Interscience, 1992); "Molecular Machinery and Manufacturing with Applications to Computation" (1991) MIT doctoral thesis; "Molecular tip arrays for molecular imaging and nanofabrication" (1991) 9 *Journal of Vacuum Science and Technology-B* 1394; *Exploring Future Technologies. Doing Science* (New York: Prentice Hall, 1991); K.Eric Drexler, Chris Peterson, & Gayle Pergamit, *Unbounding the Future: The Nanotechnology Revolution.* (New York: William Morrow, 1991); *Technologies of Danger and Wisdom. Directions and Implications of Advanced Computing* (Norwood, New Jersey: Ablex, 1989); *Biological and Nanomechanical Systems: Contrasts in Evolutionary Capacity. Artificial Life* (Reading, Massachusetts: Addison-Wesley, 1989); *Rod logic and thermal noise in the mechanical nanocomputer. Molecular Electronic Devices* (Amsterdam: North-Holland, 1988); "Nanotechnology and future supercomputing. Proceedings of the Third International Conference on Supercomputing. International Supercomputing Institute" (1988); "Nanomachinery: Atomically precise gears and bearings. IEEE Micro Robots and Teleoperators Workshop" (Hyannis, Massachusetts: IEEE, 1987); *Molecular Machinery and Molecular Electronic Devices II* (New York: Marcel Dekker, 1987); "Molecular Engineering: Assemblers and Future Space Hardware" (1986) 86 *American Astronautical Society*-AAS 415; "When Molecules Will do the Work" (November 1982) *Smithsonian Magazine;* "Molecular engineering: An Approach to the Development of General Capabilities for Molecular Manipulation" (1981) 78(9) *Proc. Natnl. Acad. Sci. U.S.A.* 5275. The term nanotechnology was first used by Norio Taniguchi, from the University of Tokyo. Taniguchi, applied the term to machining perceived engineering at the micrometer scale at a new sub-micrometer level, which he dubbed "nano-technology". Douglas Hulhall, *Our Molecular Future: How nanotechnology, robotics, genetics and artificial intelligence will transform our world* (Amherst: Prometheus Books, 2002).

[29] K. Eric Drexler, "Nanotechnology: From Feynman to Funding" (2004) 24:1 Bulletin of Science, Technology and Society 21 at 23 [Drexler, "From Feynman"].

[30] See *e.g.* Joy *supra* note 3 and The Etc. Group *supra* note 19.

[31] As will become evident in the sections to follow, it is conceivable that this very possibility is what has

Given the mystique and intrigue surrounding the original Feynman vision, it is not surprising to learn that many specialists working in more mundane fields have leveraged the initial goodwill attached to the nanotechnology label. As Drexler has pointed out, it has become trendy during the past ten years to label practically every new technological enterprise operating on a small scale as *nanotechnology*. Smalley explained this phenomenon in the following way: "[t]he combination of high tech gee whiz, high social impact, and economic good sense gives the dream of nanotechnology the ability to inspire our nation's youth toward science unlike any event since Sputnik."[32]

To get a sense of the scope of application in the current use of the word one need only consider the following enumerated list, offered recently to the President's Council of Advisors on Science and Technology:

> … pigments in paints; cutting tools and wear resistant coatings; pharmaceuticals and drugs; nanoscale particles and thin films in electronic devices; jewelry, optical and semiconductor wafer polishing.[33]

While these endeavors certainly fall within the realm of "manipulating and controlling things on a small scale,"[34] they are plenty-far-from-the-bottom and do not purport to achieve anything like the precision of atom-by-atom control originally proposed by Feynman. A broad prohibition of the items on the enumerated list would do little to protect us from the dangers that might one day accompany a continued quest for atom-by-atom control.

Thus the stakeholders in and around this new and exciting field must quickly come to terms with something that the lawyers have known all along — namely, that definitions carry important consequences. Perhaps a more realistic example of the regulatory consequences of defining nanotechnology (at least in the immediate future) arises in the case of federal or private sector funding opportunities available for companies working with materials falling within a defined nanoscale. One can imagine, for instance, that the definition would matter a great deal to an enterprise that develops individual thin-film NiFe ferromagnets.[35] According to recent studies,

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motivated Richard Smalley to expend so much effort in the popular press trying to demonstrate that the construction of nanobots is impossible.

32 Richard Smalley, "Nanotechnology, Education, and the Fear of Nanobots" (2000) in Mihail Roco & William Sims Bainbridge eds., *Societal Implications of Nanoscience and Nanotechnology* — 2000 NSET Workshop Report, (Dordrecht: Kluwer, 2001), online: World Technology Evaluation Centre <www.wtec.org/loyola/nano/societalimpact/nanosi.pdf>.

33 Dr. Samuel Stupp of Northwestern University offered these examples in a presentation made to the President's Council of Advisors on Science and Technology on March 3, 2003, "Nano-Biomaterials" (President's Council of Advisors on Science and Technology, 3 March 2003) [unpublished], online: PCAST <http://www.ostp.gov/PCAST/PCAST%203-3-03%20S%20Stupp%20Slides.pdf> at slide 23; "Drexler, "From Feynman", *supra* note 29.

34 These are Feynman's words.

35 A ferromagnet is composed of ferromagnetic materials, which are materials that are able to spontaneously magnetize, where the microscopic magnetized areas are aligned by an external magnetic field. The

it is not possible to scale individual ferromagnets below 10 nanometers.[36] To the company that produces these individual thin films, it would matter a great deal whether the definition included technologies working at "a scale not exceeding 10 nanometers" rather than "a scale not exceeding 100 nanometers."

While, in some ways, nano's nomenclature has tended towards being over-inclusive, there is perhaps a more recent trend in the other direction. In an article titled, "From Feynman to Funding," Drexler offers an interesting chronicle of what he sees as a gradual repudiation of the original Feynman vision, noting its full presence when President Clinton first announced the NNI in 2000, and then detailing its subsequent marginalization during various congressional hearings and NNI workshops following the bad press the original vision has received from Joy, Crichton and more recently, Richard Smalley.

In addition to the bad press surrounding nanobots, it is thought that some nanoscale technologists have disassociated from the Feynman vision because it had the makings of a bad business plan; *it* promised more than *they* could soon deliver. As Drexler describes it, all of this gets *very* political:

> For nanoscale technologists to unburden nanotechnology while claiming its prestige, the Feynman vision had to be accepted as a slogan but rejected as a present goal and a future reality. And indeed, an Institute of Electrical and Electronics Engineers sponsored evaluation of the NNI states that '[t]he notion of the self-replicating assembler has become the defining characteristic of the split in an otherwise unified nanotechnology community.'[37]

## III. The Politics of Dancing

Back to where this article began.

> 'There's plenty of room at the bottom.' But there's not *that* much room.[38]

What, then, is the significance of Smalley's rejoinder?

First, there is the scientific answer. From the perspective of scientific discourse, Smalley's aim is to persuade his audience that the actual construction of

ferromagnet piece thus becomes a permanent magnet. Ferromagnet, *Wikipedia*, online: Wikipedia <http://en.wikipedia.org/wiki/Ferromagnet>.

36 Franklin Monzon, D.S. Patterson & Michael Roukes, "Characterization of individual nanomagnets by the local Hall effect" (1999) 195 J. Magnetism and Magnetic Materials 19 at 24, online: California Institute of Technology — Roukes Group <http://www.its.caltech.edu/~nano/papers/monzon2.pdf>.

37 "Drexler, "From Feynman", *supra* note 29 at 23.

38 "Smalley, "Of Chemistry", *supra* note 1.

self-replicating nanobots is not possible. As he put it in his article for *Scientific American*:

> Manipulator fingers on the hypothetical self-replicating nanobot are not only too fat; they are also too sticky: the atoms of the manipulator hands will adhere to the atom that is being moved. So it will often be impossible to release this minuscule building block in precisely the right spot.
>
> Both these problems are fundamental, and neither can be avoided. Self-replicating, mechanical nanobots are simply not possible in our world. To put every atom in its place — the vision articulated by some nanotechnologists — would require magic fingers. Such a nanobot will never become more than a futurist's daydream.[39]

In essence, Smalley is asserting that there is plenty of room to maneuver at the nanoscale, but there is not enough room to achieve the kind of precision required to "put the atoms down where the chemist says."[40]

There is, of course, a much different way to characterize the significance of Smalley's famous remark. The *rhetorical force* of his statement — that there is plenty of room, but not *that* much room — can be understood in a political context as well.[41] As Feynman had prognosticated in 1959, there are economic incentives at stake here. When it comes to funding a scientific project of this magnitude, there may not be *that* much room. Not for two such fundamentally different, competing conceptions of nanotechnology and its future. A split in the nanotechnology community has become quite evident; the nano-network has become divisive. As an illustration, we consider in this section the most recent series of exchanges between Smalley and Drexler.

In a manner not unusual for a scientist of the highest order, Smalley commences the exchange in his *Scientific American* article, pointing out the subtlety of his field by way of metaphor:

> In a chemical reaction between two 'consenting' molecules, bonds form between some of the atoms in what is usually a *complex dance* involving motion in multiple dimensions. Not just any two molecules will react. They have to be right for each other. And if the chemistry is really, really good, the molecules that do react will all produce the exact product desired.[42]

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[39] *Ibid.*
[40] These are Feynman's words. Feynman, *supra* note 4 at para. 63.
[41] Of course, we are *not* suggesting that Smalley himself intended any such meaning in his actual allusion to the Feynmen quotation.
[42] "Smalley, "Of Chemistry", *supra* note 1 at 76.

Whether Smalley is excessive in his use of the "dance of love" metaphor is perhaps a matter best left to individual readers. Despite its shortcomings, metaphor has always held a valuable place in science,[43] as it has in law and policy.[44] And — right or wrong — Smalley's essential point was quite clear:

> All these atoms must move in a precise way to ensure that the result of the reaction is the one intended. In an ordinary chemical reaction five to 15 atoms near the reaction site engage in *an intricate three-dimensional waltz* that is carried out in a cramped region of space measuring no more than a nanometer on each side.[45]

In other words, there is not *that* much room at the bottom. According to Smalley, something like additional manipulator arms would be necessary for each one of these atoms in order to have complete control of all the goings-on that occur at the reaction site.

With all of this, Smalley offers his moral of the story, once again, in the language of metaphor:

> Like the *dance of love*, chemistry is a waltz with its own step-slide-step in three-quarter time. Wishing that a waltz were a meringue — or that we could set down each atom in just the right place — doesn't make it so.[46]

Needless to say, Drexler — whose dance-card was the direct target of these rhetorical remarks — was unimpressed. In the years since, Drexler has issued a number of press releases and open letters, prodding Smalley to retreat from this position. In one recent press release, he says of Smalley:

> He offers vehement opinions and colorful metaphors *but no relevant, defensible scientific arguments, hence no basis for crucial policy*. Smalley has struggled for years to dispel public concerns by issuing false denials of the capabilities of advanced nanotechnologies. That campaign has failed. It should be abandoned.[47]

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[43] George Lakoff & Mark Johnson, *Metaphors We Live By,* 2d ed. (Chicago: University of Chicago Press, 2003); Daniel Rothbart, "The Semantics of Metaphor and the Structure of Science" (1984) 51 Philosophy of Science 595.

[44] See *e.g.* Ian R. Kerr, "Mind Your Metaphors: An Examination of the Inefficacy Argument as a Reason against Regulating On-line Conduct" in *Ethics and Electronic Information in the 21st Century,* Lester Pourciau, ed., (West Lafayette, Indiana: Purdue University Press, 1999) 231; Ian R. Kerr, "Pre-Natal Fictions and Post-Partum Actions" (1997) 20 Dalhousie Law Journal 237.

[45] Baum, *supra* note 12 (emphasis added).

[46] *Ibid.* (emphasis added).

[47] "Nobel Winner Smalley Responds to Drexler's Challenge" *Foresight Institute* (1 December 2003), online: Foresight Institute <http://www.foresight.org/press.html#20031201> (emphasis added).

Much to Drexler's credit, the above passage is neutral and dispassionate, as one might expect of peers debating scientific principles. But that is not how their debate has generally proceeded. It is worth considering a few additional *soundbytes* snipped from this so-called scientific discourse:

*Smalley:* "We should not let this fuzzy-minded nightmare dream scare us away from nanotechnology. … NNI should go forward."[48]

*Drexler:* "Your reliance on this straw-man attack might lead a thoughtful observer to suspect that no one has identified a valid criticism of my work. For this I should, perhaps, thank you."[49]

*Smalley:* "The central problem I see with the nanobot self-assembler then is primarily chemistry. If the nanobot is restricted to be a water-based life-form, since this is the only way its molecular assembly tools will work, then there is a long list of vulnerabilities and limitations to what it can do. If it is a non-water-based life-form, then there is a vast area of chemistry that has eluded us for centuries … Please tell us about this new chemistry."[50]

*Drexler:* "[T]o visualize how a nanofactory system works, it helps to consider a conventional factory system. The technical questions you raise reach beyond chemistry to systems engineering."[51]

*Smalley:* "I see you have now walked out of the room where I had led you to talk about real chemistry, and you are now back in your mechanical world. I am sorry we have ended up like this. For a moment I thought we were making progress.

But, no, you don't get it. You are still in a pretend world where atoms go where you want because your computer program directs them to go there."[52]

*Drexler:* "Some chemists with careers tied to the old paradigm (based on random molecular motion in liquids) seem confused and threatened by this different and more powerful approach. … Members of the old guard instead have assured one another that MNT is 'an impossible, childish fantasy' — in short, that there is nothing to learn. Having failed to

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48 Baum, *supra* note 12.
49 *Ibid.*
50 *Ibid.*
51 *Ibid.*
52 *Ibid.*

master the basic principles of MNT, they see its revolutionary promise and dangers as false, and try urgently to dismiss it."[53]

*Smalley:* "You and people around you have scared our children. I don't expect you to stop, but I hope others in the chemical community will join with me in turning on the light, and showing our children that, while our future in the real world will be challenging and there are real risks, there will be no such monster as the self-replicating mechanical nanobot of your dreams."[54]

The above compilation of *soundbytes* from the exchanges between Smalley and Drexler, many of which have been published in scientific journals over the past few years, is not meant to provide full coverage, nor even a summary of their scientific positions. Quite to the contrary, these remarks were purposefully selected to demonstrate that there are other things at play in these exchanges besides the testing of each other's hypotheses.

Our point is that, despite Drexler's very good intentions and his deep concerns about the future of humanity, this is not *mere* scientific discourse. It is, to play on Smalley's metaphor, the *politics of dancing*. In addition to a tango of egos, there is a turf war between scientific disciplines. There is also the fight for funding. Perhaps most important of all, there are ontological commitments and ideologies clearly at stake. As Lawrence Lessig has observed, *this is as much about ideas as it is about matter*.[55] These are points worth making since many of these things seem to have gone practically unnoticed by some laypersons, scientists, and policy makers who naively consider this debate to centre exclusively on the truth about matter.

To date — when one considers the diversity of nanotechnology research under investigation across the globe — the high profile and well publicized debate between Drexler and Smalley has had a disproportionate affect on the U.S. nanotechnology policy-making process. This became evident during the congressional hearings devoted to the consideration of H.R. 766, *The Nanotechnology Research and Development Act of 2003*.[56] Although neither Drexler nor Smalley personally testified before the *House Committee on Science* during these hearings — both have previously been called upon to do so on several other occasions — each of their views and positions were very clearly and quite unmistakably articulated by colleagues and allies from within their own narrow networks of influence, as the various stakeholders jockeyed for position.

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[53] Foresight Institute, "Is the Revolution Real?" online: Foresight Institute <http://www.foresight.org/NanoRev/istherev.html>.

[54] Baum, *supra* note 12.

[55] Lawrence Lessig, "Stamping Out Good Science," *WIRED* 12.07 (July 2004), online: Wired <http://www.wired.com/wired/archive/12.07/view.html?pg=5?tw=wn_tophead_6>.

[56] U.S., Bill H.R. 766, *The Nanotechnology Research and Development Act of 2003*, 108$^{th}$ Cong., 2003 (enacted) [*Nanotechnology Act*].

It was not difficult to identify a trend: scientists with alliances to universities and federal agencies tended to follow Smalley's dismissal of the "nanobot". For example, Carl Batt of Cornell University provided testimony that practically mimicked Smalley's characterization of "runaway technologies" and "self-assembling autonomous machines smaller than a bacterium" as existing "*only in an artist's imagination.*"[57] Likewise, Smalley's colleague, Dr. Vicki Colvin of Rice University, opined that scenarios such as those in Crichton's *Prey* are being used as a distraction and recommended that a distinction must be drawn between science fiction and science fact.[58] On the other side, the hearings included testimony from two *Foresight Institute* board members,[59] both of whom were present to echo Drexler's concerns.

Others, such as political theorist Langdon Winner, encouraged public participation as "wise policy would try to stimulate understanding of the implications of the technology on a broad scale, fostering widespread study and discussion open to everyone."[60] Despite being cast as "science fiction", there is little question that both Smalley and Drexler's concerns were influential at the Committee stage of the hearings. This is reflected in the end result; the enacted Bill includes a provision requiring an assessment of the needs for guidelines and standards for the development of safe nanotechnology applicable to "self-replicating nanoscale machines or devices" be conducted within 6 years.[61]

## IV. Actor-Network Theory

Sociologists of science have, for quite some time, held that science is the product of collective action and that the ideas of individual scientific actors are best understood within the context of larger scientific networks.[62] Actor-Network theory, as it is called by some,[63] is perhaps a useful heuristic when considering the policy implications of relying on a particular scientific discourse such as the exchange between Smalley and Drexler.

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[57] U.S., *The Nanotechnology Research and Development Act of 2003: Hearing on H.R. 766 Before the House Committee on Science*, 108th Cong., (2003), online: United States House of Representatives <http://www.house.gov/science/hearings/full03/mar19/batt.htm> (emphasis added).

[58] U.S., *The Societal Implications of Nanotechnology: The Nanotechnology Research and Development Act of 2003: Hearing on H.R. 766 Before the House Committee on Science*, 108th Cong., (2003), online: United States House of Representatives <http://www.house.gov/science/hearings/full03/apr09/colvin.htm> [Societal Implications].

[59] Christine Peterson and Ray Kurzweil each testified on April 9th, 2003.

[60] Societal Implications, *supra* note 58, online: United States House of Representatives <http://www.house.gov/science/hearings/full03/apr09/winner.htm>.

[61] *Nanotechnology Act*, *supra* note 56, s. 8(c)(1).

[62] Bruno Latour, *Science in Action* (Cambridge, Mass: Harvard University Press, 1987) [Latour, "*Science in Action*"].

[63] See *e.g.* Latour's forthcoming book, *Actor Network Theory — A Personal Guide to Sociology* (Oxford: Oxford University Press).

As is true in other scientific fields, various nanotechnology actors have engaged in a network of collective fact building. Whether or not a particular statement about nanotechnology is perceived as fact will to some extent depend on what others make of it — some scientific claims are accepted within the scientific community while others are modified, or altogether abandoned.[64] To take a rather obvious example, since the time that Drexler publicly articulated his vision of nanotechnology, it has been wholly accepted by some actors, while largely rejected or modified by others.[65]

According to Latour's characterization of the actor-network theory, the scientific fact-builder must do two things in order to protect the integrity of a scientific claim: (i) enroll others into the actor-network so that they take part in the construction of the fact; and (ii) control the behaviour of other actors in the network to ensure that their actions are predictable.[66] While neither of these two things is usually accomplished directly, Latour has pointed out a number of translation techniques and tactics that can be employed by actors to enroll other actors into favourable positions.[67] Some of these include catering to the needs of others, reshuffling interests and goals, and introducing strategic detours.[68] The use of a particular technique may shift depending on the strength of the rhetoric.[69]

Although Smalley and Drexler have both been relatively successful in employing a number of these techniques within their own scientific networks, in the end, neither one has completely succeeded in controlling the behavioural responses of others — especially those operating in parallel or overlapping networks. This has resulted in unpredictable actions from other players, such as Joy (in computer science) and Crichton (in science fiction).

Not having achieved a clear scientific consensus, still other actors in the field are attempting to further transform the nano-network. Included among them are other scientists and academics who disagree with Drexler's expectations and outlook, as well as corporate research and development departments and venture capitalists who have not been able to find a way to profit immediately from

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[64] "Latour, "*Science in Action*", *supra* note 62.

[65] Very often this is done to suit one's own scientific expectations and beliefs. For example, Kurzweil, Minsky, Reynolds, Peterson, and Merkle all largely accept Drexler's vision of Nanotechnology, whereas others such as Smalley and Slaughter have rejected it. Typical reactions to Drexler are of the sort exhibited by the head of NASA's nanotechnology program, who accused Drexler of "spinning science fiction." He states that Feynman was responsible for the emergence of nanotechnology and "that is what all serious people follow. I want to distance myself from anything Drexler talks about…most people who work in the lab don't subscribe to anything Drexler says. In many cases, it is like science fiction. Who knows if it will turn out?" [quoted in Celia Selin, "Expectations in the Emergence of Nanotechnology", online: Copenhagen Business School <http://old.cbs.dk/departments/mpp/forskerskolen/calendar/Selin.pdf> at 7.]

[66] "Latour, "*Science in Action", supra* note 62 at 108.

[67] *Ibid.*

[68] *Ibid.*

[69] See Part III of *Science in Action, ibid.* at 103.

Drexler's promulgation of Feynman's long-term vision. Still, Smalley and Drexler seem to have retained some control of the nano-network. Consequently, the mainstream debate continues to centre on the feasibility of molecular manufacturing while the broader social, economic, ethical, and policy implications of this apparently revolutionary technology remain largely at the margins.

In our view, this is not the best way to develop appropriate regulatory structures for nanotechnology. This type of rhetorical exchange is not the best enabler of sound policy and planning.

## V. Mend the Gap

Policy-making is inherently a challenging task — a task made more difficult when faced with future uncertainties. In the face of rapid change, it is not good enough to simply debate about what we think is and is not scientifically possible *today*. Nor is it sufficient to state that "[t]here is no scientific evidence to support the notion that nanoparticles and nanotubes — the main components of many nanotech-based products — pose risks on human health and the environment."[70] While such statements, if true, are an important claim in advancing the argument that the perceived risks of nanotechnology are likely to be overestimated and overrated by mass media and the like, the policy debate does not and ought not end with the conclusions of our science *de jour*.

Rather, we must learn how to co-ordinate science and technology policy so that we can plan for alternative futures. This will involve broadening the debate beyond physicists, chemists and engineers. As the authors of a recent report noted:

> As the science of NT leaps ahead, the ethics lags behind. Activist groups have appropriately identified this gap, and begun to exploit it. We believe that there is danger of derailing NT if serious study of NT's ethical, environmental, economic, legal, and social implications does not reach the speed of progress in the science.[71]

Minding the gap is indeed an important first step. Mending it, however, is the more challenging next step.

In this section we briefly describe a well known alternative to Drexler and Smalley's point/counterpoint discourse. By reiterating this alternative approach, we hope to remind those interested in the ethics and science of nanotechnology that there are other discussions to be had. Rather than focusing primarily on competing scientific visions about the feasibility of molecular manufacturing, we hope to

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[70] Emmanuelle Schuler, "Perception of Risks and Nanotechnology", online: TU-Darmstadt — Institut für Philosophie <http://www.ifs.tu-darmstadt.de/phil/Schuler.pdf>.
[71] "Mind the Gap", *supra* note 19.

connect that discourse to existing techniques that have been used in other fields to identify and assess the bridge between our possible futures and the present.

What we are promoting is what one future studies author has described as:

> *a code to communicate between social actors in science, technology and society* … a combined analysis and communications process in which informed parties and stakeholders participate in a forward-looking exercise to identify the most important issues in the emerging S&T portfolio.[72]

*Foresighting,*[73] as it is sometimes called, is a methodology for examining the long-term future and finding answers for the present as a means of guiding technology policy. It represents an historical shift from short-term to long-term thinking; from past-oriented to future-oriented; from linear to non-linear 'system' thinking;[74] and from an either/or to a multiple option mindset.[75] It has been defined as:

> …the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging of generic technologies likely to yield the greatest economic and social benefits.[76]

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[72] Quoted in Jan Kozlowski, "Adaptation of Foresight Exercises in Central and Eastern European Countries" (Paper presented to the United Nations Industrial Development Organization's Regional Conference on Technology Foresight for Central and Eastern Europe, 4-5 April 2001), online: UNIDO <http://www.unido.org/userfiles/kaufmanC/Koslowskipaper.pdf> at 13 (emphasis added).

[73] The first time the term Foresight was used in a book in the context of science and technology policy was in 1984 by John Irvine and Ben Martin in their book *Foresight in Science: Picking the Winners* (London: Dover Frances Pinter, 1984). *See* generally: Richard Slaughter, "A Foresight Strategy for Future Generations" (1997) 29:8 *Futures* 732; Richard Slaughter, "Foresight beyond Strategy: Social Initiatives by Business and Government (1996) 29:2 *Long Range Planning* 156; Richard A. Slaughter, *The Foresight Principle: Cultural Recovery in the 21st Century* (London: Adamantine, 1995) [Slaughter, "Foresight Principle"]; Richard Slaughter, "The Knowledge Base of Futures Studies as an Evolving Process" (1996) 28:99 *Futures* 799; Denis Loveridge, "Foresight and its Emergence", PREST 1998; Ben Martin, "Technology Foresight: Capturing the Benefits from Science-Related Technologies" (1996) 6:2 *Research Evaluation* 167; Ben Martin, "Foresight in Science and Technology" (1995) 7:2 *Technology Analysis & Strategic Management* 139 [Martin, "Foresight in Science"]; OECD, "Technology Foresight:A Review of Recent Government Practices" (1995); Hariolf Grupp & Hal Linstone, "National Technology Foresight Activities Around the Globe — Resurrection and New Paradigms" (1999) 60 *Technological Forecasting and Social Change* 85.

[74] As Kozlowski points out "it is no coincidence that foresight was born in the 1970's when the development of the system approach was accelerated." In the early 1970's, several key systems books were published: Jay Forrester, *World Dynamics* (Cambridge: MIT Press, 1973); George Klir, *Trends in General System Theory* (New York: Wiley-Interscience, 1972); and Mario Bunge, *Treatise on Basic Philosophy,* vol. 4 Ontology 11: A World of Systems (Dordecht, Boston: Reidel, 1979).

[75] *Ibid.*

[76] Martin, "Foresight", *supra* note 73 at 140.

This approach involves "[a] process by which one comes to a fuller understanding of the forces shaping the long term future … which should be taken into account in policy formulation, planning and decision making."[77]

'Foresighting' can be distinguished from 'forecasting.' Forecasting is the passive attempt to diagnose or predict future events.[78] Smalley's *Scientific American* article, for example, merely forecasts that self-replicating nanobots cannot and will not be part of our future. Conversely, foresighting aims to actively change or create the future by linking it to the present. It focuses on the challenges of tomorrow, today. Thus, "the major difference between foresight and forecasting is that in forecasting the conclusions for today are missing."[79] The process of foresighting is premised on the assumption that the future is not fixed and that alternative futures exist.[80]

Foresighting can be used in various ways. According to Slaughter, there are four major applications: "[i] assessing possible consequences of actions… [ii] anticipating problems before they occur … [iii] considering the present implications of possible future events … [and] [iv] envisioning desired aspects of future societies."[81] As the literature points out, foresighting as a tool for 'decision-shaping' rather than 'decision-making' offers many benefits including: engaging policy-makers and experts in actively planning for the future, identifying potential problems early, verifying expectations and examining trends, bringing people together to create a suitable future, strengthening existing networks, and educating the public on urgent future-related issues.[82]

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[77] Joseph Coates, "Foresight in Federal Government Policy Making" (1985) *Futures Research Quarterly* 1 at 10.

[78] Kerstin Cuhls, "Can Foresight as a Policy Instrument Contribute to Technology Policy in Less Favoured Regions?" (Poster paper presented to the Euroconference on Technology Policy and Less Developed R&D Systems in Europe, 17 October 1997), online: INTECH Publications <http://www.intech.unu.edu/publications/conference-workshop-reports/seville/cuhls.pdf>.

[79] Kerstin Cuhls quoted in Jan Kozlowski, *supra* note 72 at 14.

[80] According to this definition, it is difficult to imagine members of Smalley's network engaging in foresighting around the social implications of molecular assemblers since they think them to be impossible. Whether Drexler's network is in fact truly engaged in the practice of "foresighting" as described above is less easily determined. As stated above, the process of foresighting is premised on the assumption that that the future is not fixed. Drexler has repeatedly spoken of "The Coming Era of Nanotechnology." Likewise, the Foresight Institute states its mission in terms of preparing for "the coming ability to build materials and products with atomic precision." To his end, Feynman is usually quoted for the view that this is "a development which I think cannot be avoided". According to the Foresight Institute, "[t]he current world-wide surge in nanotechnology research reinforces his conclusion." [http://www.foresight.org/]. Operating on the assumption that molecular manufacturing is *inevitable* (although it is not entirely clear that this is what the Foresight Institute is doing) would undermine the foresighting methodology in precisely the same way that the assumption that molecular manufacturing is *impossible* does. Both approaches risk shaping future possibilities that might otherwise be avoided or, alternatively, risk the omission of future possibilities that might otherwise be considered.

[81] "Slaughter, "Foresight Principle", *supra* note 73 at xvii.

[82] Ron Johnston, "The State and Contribution of International Foresight: New Challenges" in EC IPTS-JRC eds., *The Role of Foresight in the Selection of Research Policy Priorities Conference Proceed-*

Foresighting could have a positive impact on nanotechnology policy by providing a means for analyzing its broader social and economic implications. While some believe that nanotechnology has the potential to eliminate the problem of resource scarcity, others have pointed out that a technology which allows that 'anything can be made from anything' is sure to have an impact on our ecological systems.[83] Similar considerations will arise in the context of economics. For instance, unless nanotechnology offers a solution to the problem of inflation, we should not necessarily assume that near costless materials' production will necessarily result in decreased prices.[84] A foresighting methodology is needed to commence an assessment of nanotechnology's potential impact on these and other core socio-economic structures.

For example, certain visions of nanotechnology, if realized, could lead to significant economic disruption.[85] Substantially revised or perhaps even alternative economic systems might one day be required to ensure that the fruits of nanotechnology (like some of the information technologies that preceded it) are not short-lived. Similar considerations might be necessary to avoid a proliferation of existing disparities in wealth and power, and the creation of new divides between the haves and have-nots. All of these things indicate that we need to further develop a set of methodologies that will help us to identify and assess the bridge between our possible futures and the present.

## VI. Building a Broader Nano-Network

Scientific forecasting, conceptual modeling, and the testing of hypotheses in the laboratory — though key to a bright future — cannot provide sufficient social safeguards for a science said to have the potential to revolutionize our ability to control and manipulate matter. Mending the gap requires the development of a broader nano-network.

Instead of standing on the sidelines, cheering-on a combative and adversarial scientific arm-wrestling match, diverse groups of social actors ought to assemble in an international arena to examine potential profits and pitfalls of the technologies

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ings, Report EUR 204006 EN, online: Turkish Academy of Sciences <http://www.tuba.gov.tr/FS-ResPrior%20eu.pdf> at 99 [Johnston].

[83] Richard Slaughter, "Reinventing the Future: Foresight and the Rise of Nanotechnology", online: World Futures Studies Federation <http://www.wfsf.org/docs/SLAUGHTER.pdf> (discusses several socio-economic implications of advanced nanotechnology).

[84] In fact, in the early stages of nanotechnology, costs of goods and services will increase because they will likely carry a surtax to allow nano-innovators to recoup research and development expenditures. See David Berube, "Nanosocialism" *NanoTechnology Magazine* 2:4 - 2:8 (April to August 1996), online: University of South Carolina English Faculty <http://www.cla.sc.edu/ENGL/faculty/berube/nanosoc.htm>.

[85] *Ibid.* See also Christine Peterson, "Molecular Manufacturing: Societal Implications of Advanced Nanotechnology" Testimony given to the U.S. House of Representatives Committee on Science (April 9, 2003), online: House Committee on Science <http://www.house.gov/science/hearings/full03/apr09/peterson.htm>.

that miniaturize from as many different angles and perspectives as possible — with the aim of consensus building. As one Australian professor put it, true foresighting requires us to build an 'epistemic community' founded on "a number of principles around which the community members inter-subjectively construct a consensus."[86] These principles would include agreed-to methods and models for assessing and understanding causal relationships, common language and jargon, and political values concerning the policy implications and what policy choices should be preferred.[87]

Though, to date, there has been a limited move in that direction,[88] there remain relatively few working groups and networks investigating nanotechnology. Two such examples include the *Working Nanotechnology Group* in the United Kingdom[89] and the *Australian Nanotechnology Network.*[90] Although others exist, most of these networks are relatively small and predominantly feature only national members. Consequently, they are less easily able to exert social influence in the international arena.[91] Moreover, many of these networks focus almost exclusively on research and development, with only a few actively seeking to address the social, ethical, and policy implications of nanotechnology.

Although the presence of the existing nanotechnology networks is vital for the growth and comprehension of the science of nanotechnology, the ability of such networks to systematically investigate the future *social* impact of nanotechnology requires further strengthening. Until such networks are established, the politically-charged discourse between individuals such as Drexler and Smalley, both of whom have testified before the United States Congress, will continue to dominate the policy-making process.

Although some foresighting techniques currently employed in other contexts rely primarily on experts, many believe that a more complete methodology ought to include a broader range of participants from the social sciences, the humanities and the arts. The general public can and ought also to play a role in understanding and analyzing the social implications of various foresighting activities. This type of active and inclusive participation not only generates excellent opportunities for

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86 Johnston, *supra* note 82 at 110.

87 *Ibid.*

88 See "Survey of Networks in Nanotechnology," released October 2003, available at: <http://europa.eu.int/comm/research/industrial_technologies/pdf/euronanoforum_surveyofnetworks.pdf> (accessed 12 August 2004).

89 <http://www.nanotec.org.uk/> (accessed: 12 August 2004).

90 <http://www.ausnano.net/> (accessed: 12 August 2004). See also Japanese Nanotechnology Research Institute: <http://unit.aist.go.jp/nanotech>; Russian Society of Scanning Probe Microscopy and Nanotechnology: <http://www.nanoworld.org/english/confer.htm>.

91 One reliable measure of the strength of a network is the level of media exposure and coverage received by it and its members. For example, the website of the Working Nanotechnology Group cites only eight incidents of media coverage in 2003. This is in sharp contrast to the media coverage received by the Foresight Institute headed by Drexler which receives a wealth of independent media coverage and exposure both independently and through internally organized conferences and symposiums.

public education and consultation about possible future events, but also enhances an expectation that "the rationality as well as the legitimacy of political decisions can be improved".[92] As Cuhls and Grupp point out,

> Discursive approaches make for more rationalized discussions, because they focus on the need to provide arguments. They introduce reasons as a standard for political discussion. Therefore, they correct the strategic (party) intellectuality and argumentative propaganda which is common in the public (mass media) confrontations.[93]

In contrast to the domain of experts — where it is possible, advertently or inadvertently, for researchers to promote their own ideologies, interests and agendas through the language of science — extending the nano-network to include laypersons and experts from relevant non-scientific disciplines would allow for greater political transparency. It might also promote a more informed and actively engaged public whereby "collective knowledge and the efficient performance of all actors in society and their capability to exchange information result in a steering resource similar to power or money."[94] An approach that creates a broader nano-network, involving other social actors in discussions and decision-making about the future regulation of nanotechnology, would enhance legitimacy and foster public trust.

## VII. Conclusion

In the quest for knowledge, scientists, unlike elected officials, are not held responsible for safeguarding the public interest. They are not generally obliged to explore issues that extend beyond their own research interests,[95] nor are they required to consult with members of the public or others working beyond their own domains of expertise. Although most scientific policy is the product of negotiation and contestation,[96] such policies should not be determined primarily on the basis of contestations amongst scientists directly involved in the scientific or technological breakthrough in question. Just as progress in science is sometimes overshadowed by politics, policy choices surrounding the adoption or regulation of a

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[92] L. Heenan as quoted in Kristen Cuhls & Hariolf Grupp, "Status and Prospects of Technology Foresight in Germany after Ten Years", online: Japanese National Institute of Science and Technology Policy <http://www.nistep.go.jp/achiev/ftx/eng/mat077e/html/mat077ae.html>.
[93] *Ibid.*
[94] *Ibid.*
[95] This very often includes securing for their institutions large research grants, patents and other forms of intellectual property.
[96] As Stephen Ball states: "Policy-making is inevitably a process of bricolage: a matter of borrowing and copying bits and pieces of ideas from elsewhere, drawing upon and amending locally tried and tested approaches, cannibalizing theories, research, trends and fashions and not infrequently flailing around for anything at all that looks as though it might work" (Stephen Ball, "Educational studies, policy entrepreneurship and social theory" In Roger Slee & Gaby Weiner, eds., *School Effectiveness of Whom? Challenges to the School Effectiveness and School Improvement Movements* (London: Falmer, 1988) at 127.

particular science or technology can become clouded by the rhetorical assertions of particular scientific stakeholders. In the absence of a 'social contract' between scientists, government officials, and the public, heated exchanges between scientists must not become a policy maker's preoccupation.

Whatever place rhetoric might have in science, on its own, it is an ill-suited method for policy analysis — especially in fields where there is little consensus but great uncertainty. This is an increasingly significant consideration when one recognizes that scientific discourse is often used as a means of building powerful though divisive social networks. In the face of competition it is usually those scientific networks that are the most successful in translating their own interests on the largest scale that have the greatest impact on how a new technology is developed and implemented.[97] Likewise, the most powerful scientific networks can also have an impact on how such technologies are eventually regulated.

With this in mind, we ought to be very careful not to foster a divisive nano-network. It is suggested here that, in the face of scientific uncertainty, we ought to be oriented towards building a broader, more inclusive network that embraces actors from diverse sectors[98] and enables the development of an overlapping consensus in the shaping of future policy.

For those truly interested in the social dimensions of the technologies that miniaturize, there is *still* plenty of room at the bottom.

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[97] "Latour, "*Science in Action"*, *supra* note 62.

[98] Including academia, industry, and the public arena: Brian Rappert, "Rationalizing the Future?: Foresight in Science and Technology Policy Co-ordination", online: The University of York SATSU <http://www.york.ac.uk/org/satsu/OnLinePapers/Brian/Futures.htm>.