There is plenty of room *downstream*.
Industrial dynamics and the governance of nanomaterials

Patrick van Zwanenberg[1] and Ismael Rafols[1,2]

[1] SPRU – Science & Technology Policy Research, Freeman Centre
University of Sussex, Brighton BN1 9QE, UK

[2] Technology Policy & Assessment Center, School of Public Policy,
Georgia Institute of Technology, Atlanta, GA 30332, USA.

August 11th, 2009

The development of nanotechnologies and nanotechnology-based products has been accompanied by unprecedented attention to their potential health, environmental, and social implications. Policies to promote the 'responsible development' of nanotechnology extend beyond the traditional concerns of how best to anticipate and mitigate adverse impacts of new technologies on health and the environment. They also involve commitments to promote and support technologies that are likely to lead to socially agreed benefits and needs. (National Research Council 2006; European Commission, 2008) Such ambitions imply greater attention to the purposeful direction of the innovation process itself.

In the UK these developments are reflected in widespread support for public engagement 'upstream' in the innovation process. (Wilsdon & Willis, 2004). The aim, at least for its academic champions, is to encourage scientists to reflect on public values and aspirations about the social purposes of technology, with a hoped for subsequent influence on the articulation and pursuit of R&D problems. The term 'upstream' was not originally meant to refer only to the site of basic research but rather to those points in the innovation process where commitments to specific problems, products and applications are not yet entrenched. (Macnaghten et al., 2005) Yet, in much of the policy literature, and in practice, 'upstream' is conflated with basic research, with public engagement activities directed at R&D priority setting and funding.[1]

These efforts are certainly valuable, but we wish to argue that, by themselves, they may not be sufficient to influence trajectories of nanotechnology innovation. We focus here only on nanomaterials, which are at the core of the current policy debate, and argue that the specific *industrial dynamics* of nanomaterials have important implications for innovation governance. In particular, we argue that policy intervention is just as important further downstream in the innovation process, directed at firms manufacturing nanomaterials, at firms and sectors that potentially use those technologies, and at consumers of nano-enabled products.

Industrial dynamics: flexibility in applications and distributed innovation

The key issue regarding industrial dynamics is that manufactured nanomaterials are not consumer products to be sold to the end-user, but rather 'capital' products to be incorporated into other products manufactured by secondary firms in a variety of industries. This has two important implications. The first is that nanomaterials are *flexible* in terms of their

[1] See for example, http://www.epsrc.ac.uk/ResearchFunding/Programmes/Nano/RC/default.htm

applications. One nanomaterial can be used for a variety of different applications that can benefit from the same special electronic, optical, catalytic, chemical or physical properties of the material (Aitken et al., 2006) The second is that *innovation* is *distributed* along a lengthy and branching value chain in which nanomaterials are incorporated as 'products for process innovation'. In these long industrial networks, innovations result not only from the synthesis of novel nanomaterials, but also from novel production processes, the novel incorporation of well known nanomaterials into existing products, novel methods to incorporate nanomaterials into products, or - more rarely - into new end-user products. The distributed nature of nanomaterials innovation is illustrated graphically in Figure 1.

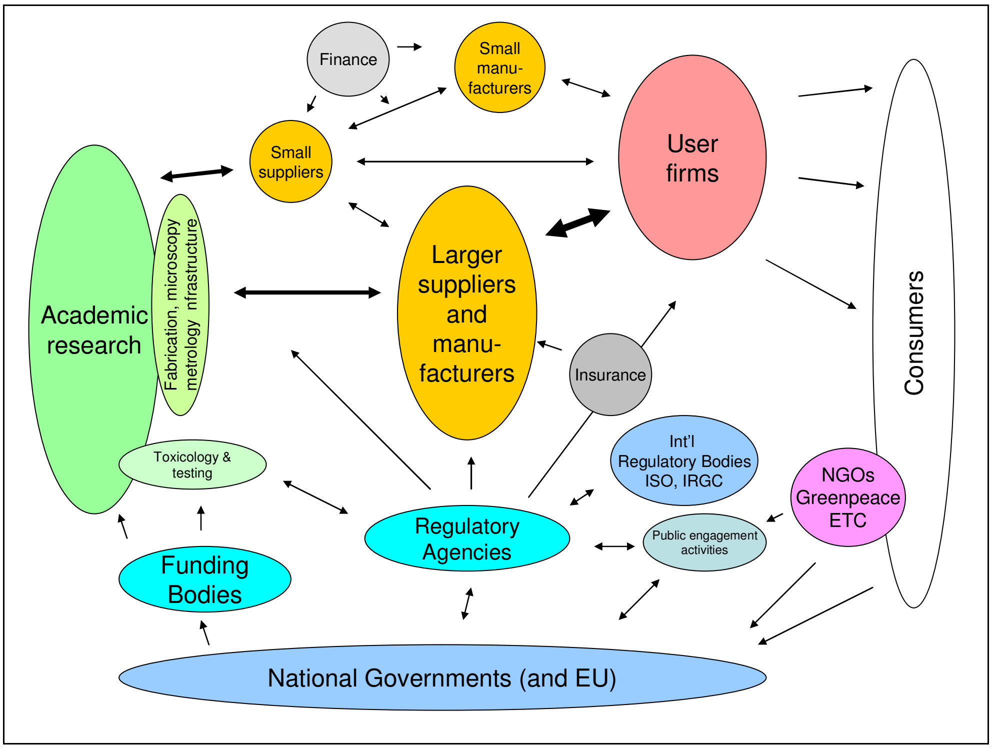

Figure 1. Generic actors and main linkages in nanomaterials innovation and governance networks.

At each of the branching 'junctures' of the nanomaterials value-chain, a given nanomaterial (such as a carbon nanotube) will be subject to multiple pressures and constraints that push, pull and shape its development in certain directions, thus constituting its *de facto* governance (Rip, 2009). These influences include the scientific and technical paradigms and routines that inform researchers' thinking, researchers and manufacturers' technological and social visions or expectations, the actions of finance and insurance markets, price and competition pressures bearing on individual firms, the entry of particular investors or firms to a sector, the presence of existing infrastructures that constrain alternative technological solutions, the activities of both industrial lobbies and civil society organisations, and broader influences such as shifting consumer cultures that inform socially acceptable performance criteria. (Dosi, 1982; Walker, 2000; Smith et al 2006)

Such influences shape a variety of technological commitments that are as likely to be formed further 'downstream' (in the sense of the value chain) within user industries and 'midstream' within manufacturing firms, as they are at the research base. The specific commitments include, amongst other things: the choice of nanomaterials that are investigated and developed, their production infrastructures, the types of applications explored, those that are then favoured, the design characteristics of nano-enabled products (e.g. whether they can be recycled), and so on. Public research, public funding and regulatory agencies play important roles in influencing those commitments, but it is the various industrial actors that configure the innovation networks (start-ups, large chemical or consumer good corporations, specialised manufacturers and user firms) that play a central role in nanomaterials governance. This is why industrial dynamics constitute such an important site for setting the direction of innovation.

There is plenty of room 'downstream'

Although the articulation of certain kinds of (publicly sanctioned) technological and social visions 'upstream' in the R&D process may be crucial in mobilizing resources, the changing configurations of the network of actors involved in innovation (including end-users), and the multiple influences on the formation of commitments, means that our ability to shift innovation in particular desired directions may be extremely limited. Yet even though we may not be able to control the *specific* outcomes of nanomaterial innovation processes, this does not mean that we cannot broadly *modulate* their development towards *generic* goals.

In particular, there is considerable scope for policy interventions 'midstream' (Fisher et al., 2006; Joly and Rip, 2008) and 'downstream' in the nanomaterials value chain, in addition to those focused at the research base. These still need to have some purchase in the early stages of innovation processes but innovation should not be assumed only to happen upstream in the value-chain. Midstream and downstream interventions might focus on those firms supplying/manufacturing nanomaterials, and creating specific applications, and the technological sectors where nano-enabled products might also be developed and/or picked up by user industries. Importantly, such policy interventions might be aimed at general social functions (e.g. sustainability in transportation and energy provision), rather than being specific in the technologies that can provide them, in this case nanotechnologies.

Consider for example, ambitions to support the development of nano-enabled photovoltaic technologies. Existing 'upstream' initiatives to support research and shape expectations could be complemented by initiatives further downstream in the value chain directed at the photovoltaic and energy industries, and at potential 'user' sectors such as housing. For example, there are potential roles for policy in: facilitating networking and knowledge flows between nanomaterial manufacturers and potential user-firms; providing grants to invest in the production capacity required; public procurement (e.g. street lighting or in government buildings) to encourage the formation of niche markets in photovoltaics; and targeted regulations, such as a requirement for the incorporation of renewable energies into certain kinds of future housing stock (Nightingale et al., 2008).

Since innovation is widely distributed and nanomaterials are flexible in terms of their applications, policy instruments designed to influence the direction of technological change should be in place throughout the value chains, up-, mid- and downstream. An understanding of how industrial networks operate, and how public policy might complement and align existing *de facto* governance processes, is crucial if we are to modulate the direction of technological change.

Acknowledgements
This article is based on research carried during a scoping study for the Royal Commission on Environmental Pollution (Nightingale et al. 2008).

References

Aitken, R. J., Chaudhry, M. Q., Boxall, A. B. A. and Hull, M. (2006). Manufacture and use of nanomaterials: current status in the UK and global trends. *Occupational medicine*, 56: 300-306.

European Commission (2008) *Commission recommendation of a code of conduct for responsible nanosciences and nanotechnologies research*. EC, Brussels 02/02/2008 C(2008) 424 final.

Fisher, E., Mahajan, R. L. and Mitcham, C. (2006). Midstream modulation of technology: governance from within. *Bulletin of Science, Technology and Society*, 26(6): 485-496.

Joly, P.-B. and Rip, A. (2007). A timely harvest. *Nature*, 450: 74.

Macnaghten, P., Kearnes, M. B. and Wynne, B. (2005). Nanotechnology, Governance, and Public Deliberation: What Role for the Social Sciences? *Science Communication*, 27(2), 268-291.

Nightingale, P., Morgan, M., Rafols, I. and van Zwanenberg, P. (2008). *Nanomaterials Innovation Systems: Their Structure, Dynamics and Regulation. Report for the Royal Commission on Environmental Pollution*. Brighton, UK, SPRU. Available at: http://www.sussex.ac.uk/spru/documents/spru-rcep-nanomaterials.pdf

National Research Council (2006), A Matter of Size. Triennial Review of the National Nanotechnology Initiative National Academies Press: Washington DC

Rip, A. (2009). De facto governance in nanotechnologies. *Unpublished.*

Smith, A., Stirling, A. and Berkhout, F. (2006). The governance of socio-technical transitions. *Research Policy*, 34, 1491-150.

Pidgeon, N. Herr Harthorn, B., Bryant, K., Rogers-Hayden, T. (2009) Deliberating the risks of nanotechnologies for energy and health applications in the United States and United Kingdom. *Nature Nanotechnology* 4: 95-98.

Walker, W. (2000) Entrapment in large technological systems: institutional commitment and power relations. *Research Policy* 29: 833-846.

Wilsdon, J. and Willis, R. (2004). *See-through science: why public engagement needs to move upstream*. London, Demos.