An integrated ecosystems approach to the design of safer nanomaterials for a nano-enabled society (EcofriendlyNano)

- A Marie Curie Career Integration Grant

Nanotechnology is a rapidly evolving enabling technology with the potential to revolutionise modern life. However, an increasing body of scientific evidence would suggest that some materials in their nano-form may induce harmful biological or environmental effects through a variety of potential mechanisms, not all of which are fully understood or quantified as yet. A key confounding factor is that nanomaterials (NMs), unlike conventional chemicals, are highly affected by their surroundings, transforming chemically, agglomerating, and/or acquiring an evolving coating of environmental or biological macromolecules, which provides them with an "environmental" identity that is derived from their initial "synthetic" identity. Factoring this context-dependence into assessment of the fate, behaviour and impacts of NMs is essential to move forward in terms of ensuring the safe implementation of nanotechnologies, and to facilitate the widespread application of NMs in environmental applications and for the improvement of ecosystems services, i.e. the processes by which the environment produces resources utilised by humans such as clean air, water, food and materials.

The aim of EcofriendlyNano was to resolve a key bottleneck in the commercial application of NMs, by re-framing the entire approach to safety-by-design as a value chain issue focussing on recovery and recycling of NMs, and understanding where additional value-add can be obtained via boosting ecosystems services such as soil, water and food quality. The overall goal was to help reduce the current regulatory uncertainty regarding NMs, which is more costly to industry than increased regulatory testing due to the difficulty of evaluating (quantifying the cost of) uncertainty and the cost associated with loss of time in bringing a product to market. To reach this goal, the project had the following three overarching objectives:

Objective 1: to "quantify" NM interactions with environmental macromolecules, including binding amounts, binding energies, dynamics and exchange, exposed functional groups and potential for interaction with cellular receptors for uptake. EcofriendlyNano assessed the interplay between NMs physicochemical properties with binding of bio- and enviro-molecules and the effect of binding on the biomolecule structure and function, as the basis for understanding and predicting NM fate in the environment.

Objective 2: To connect the nature of the adsorbed macromolecule layer with NM fate in the environment (dissolution versus persistence; transformation and ageing; uptake & localisation; and food chain impacts including inter- and intra-species signalling effects). EcofriendlyNano assessed the interplay between NMs composition, physicochemical properties (structure) with binding of biomolecules (interactions) as the basis for predicting their fate & behaviour in the environment, including impacts on ecosystems services (physiological response).

Objective 3: To connect the nature of the adsorbed macromolecule layer with NM behaviour in the environment, including direct impacts on organisms, indirect effects via secreted inter- and intraspecies signalling molecules (e.g. kairamones and allomones etc.) and ecosystems services impacts. While this was quite speculative, the ultimate objective of EcofriendlyNano was to draw parallels between the role and potential impacts of an adsorbed environmental corona including providing directions for future research activity, by comparison with the more advanced state of knowledge on biomolecules in the corona of NMs designed for direct contact with humans.

Some highlights include assessment of strategies for cleaner or benign-by-design synthesis of carbon nanotubes (WP1), assessment of nanoparticle interactions with the proteins secreted by the sentinel organism Daphnia magna (WP2 and WP5) and uptake of the particles in the absence and presence of a secreted protein corona (WP4). An interesting (and somewhat unexpected) finding from this research was that the nanoparticles coated by the secreted biomolecule corona where more toxic to the Daphnia than the uncoated particles, in part due to increased uptake and retention (persistence) of the particles (WP5) as a result of partial agglomeration in the presence of the secreted proteins. Other highlights include broadening out the domains of interest for nanosafety and nanoregulation, including addressing the hydrogeology community on the implications of nanomaterials for the Water Framework Directive (WP6).

Other highlights include the development of a framework for benign-by-design nanomaterials, and assessment of the role of nanoscale structures and nanomaterials in bioremediation and nano-geoengineering as means to repair / enhance the ecosystems services provided by natural environments such as soils and peatlands. The pioneering work on the role of secreted biomolecules in modulating the toxicity of nanomaterials to aquatic organisms such as Daphnia magna has continued, along with a detailed exploration of the role of feeding, which is a critical factor in moving particles along the gut of Daphnia, on nanomaterials toxicity have also been performed. The findings from these studies are now feeding into important revisions of the OECD guidance documents for nanomaterials safety testing in support of the revised REACH guidelines for nanomaterials issues by ECHA in mid-2017, as part of the Malta project .

Main outputs to date:

9 papers and 2 book chapters, plus several more papers in advanced drafting stage.

The project supported the career development of the PI, who transitioned from Lecturer through Senior Lecturer to Chair Professor during the course of the project, and co-funded 1 PhD student (on biochar remediation and the role of nanoscale structures in this) and 1 postdoctoral researcher whose work included development of a framework for operationalisation of responsible innovation principles and environmental risk assessment into nanomedicine, and application of life cycle assessment approaches to carbon nanotubes and their applications in a range of product types with different levels of contact with humans and the environment as part of a strategy for safer by design nanomaterials.

The concept of the environmental corona that surrounds nanomaterials immediately upon contact with aquatic, sediment or soil environments is now much more widely accepted and understood as a result of the work performed in the EcofriendlyNano project. The overall concept was taken up into several subsequent EU projects, such as H2020 NanoFASE (2015-2019) and Marie Curoe Individual Fellowships Dr. Ryo Sekine (project no. 182395 MolNANOtox, 2015-2018), Dr. Berta Bonet (project no. 706172 – NanoToX, 2017-2019, extended to 2020 due to maternity leave of the fellow), and Dr. Alexandros Chatzipavlidis (Project no. 797929, ToxEcoGraphene, 2018-2020).

Expected impact and use:

A significant challenge faced by Europe compared to the US is the lack of clear centres of excellence for nanosafety and nanoregulation. The establishment of Dr. Lynch (now Prof. Lynch) at the University of Birmingham adds to the critical mass of internationally competitive researchers active on the topic of environmental implications of NMs, and is contributing significantly to making University of Birmingham an internationally recognised centre of excellence for this field. This is recognised by the numerous EU Horizon2020 nanosafety-related projects with UoB partners, including NanoFASE, Marie Curie RISE project NanoGenTools, the newly starting EC4SafeNano and the in-negotiation project ACEnano. Prof. Lynch is also coordinating the development of the Stage 2 proposal for a Starting Community research infrastructure on nanosafety data (called NanoCommons) which will be submitted in March 2017.

The project opened new research opportunities within the area of environmental applications of NMs, in addition to the deepening understanding of safe design, implementation and recovery of NM, contributing to the scientific excellence, and leadership, of Europe in these important areas.

Europe has always been a global leader in the management and protection of the environment, and indeed has taken a leadership role in ensuring the safe implementation of nanotechnologies, via its code of conduct for responsible nanosciences and nanotechnologies research, and via the development of the REACH regulations which are now being reviewed in light of the rapid emergence of NMs in myriad application sectors.

EcofriendlyNano has enabled Prof. Lynch to increase the capacity of the School of Geography, Earth and Environmental Sciences to cooperate with stakeholders from industry, policy and regulatory bodies on event research (International Environmental Agencies, Local Authorities, European Environmental Agency, DEFRA, Health & Safety Executive etc.). Indeed, via the project, Dr. Lynch was able to establish the UK Nano-Environment Academics and Regulators Group, which has subsequently received funding from the UK Natural Environment Research Council as part of the Pathways to Impact of the CEH-UoB NERC funded Highlight Topic project on the "Tracking relevant nanomaterial transformations, exposure, uptake and effects in freshwater and soil systems" project.

Project Website: http://www.birmingham.ac.uk/research/activity/environmental-health/areas/enviro-nanoscience/index.aspx

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