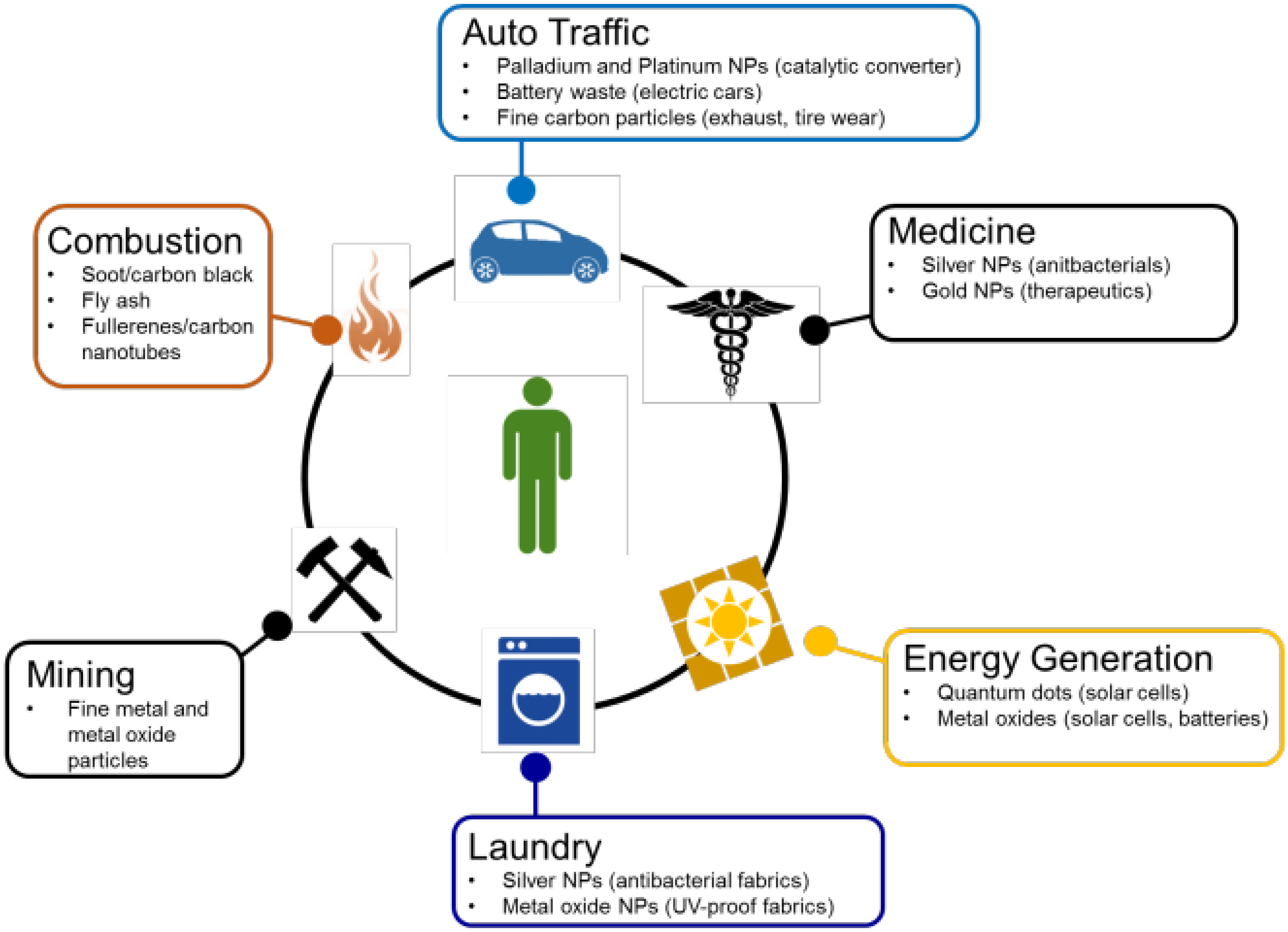
HOW NANOPARTICLES GET INTO THE ENVIRONMENT

In my previous post, I briefly touched on some of the different ways in which man-made nanoparticles can enter the environment, but here, I would like to describe a few of the most important pathways in detail. Like any chemical contaminant, nanoparticles could accidently be released into the atmosphere or nearby natural water during their production or through a factory's waste stream. By 2020, the total amount of nanomaterials produced by industry is expected to increase from 1000 to 58000 tons, making the release of nanomaterials during production a significant concern.[4] However, environmental regulations will ultimately limit the amount of nanoparticle waste that can enter the environment through dumping or accidental release. Therefore, we will focus this discussion on the two most likely pathways of nanomaterial release: release through ordinary human activities and the use of nano-enabled products.

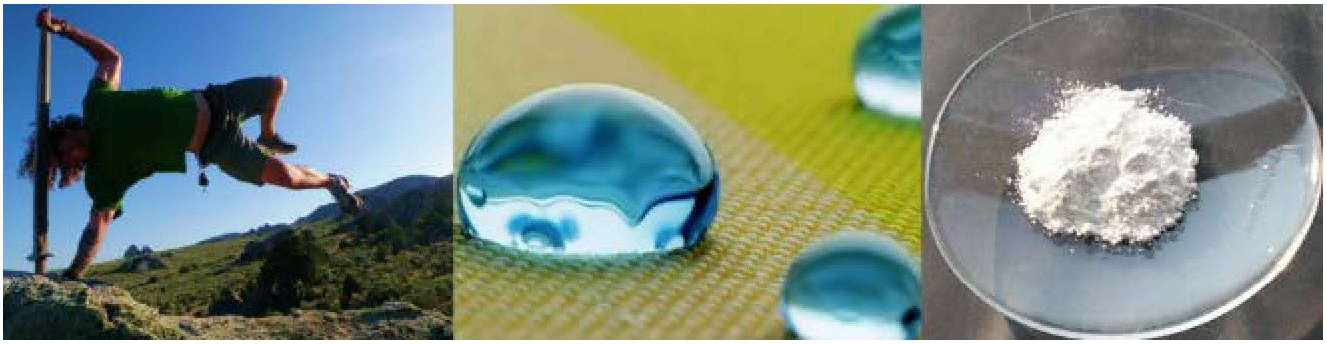
There are a number of human activities that release nanoparticles. These include burning fossil fuels, large-scale mining/demolition, and automobile traffic. Traffic emissions and fossil fuel combustion typically produce ultrafine (read: *nano*) particles of soot or carbon black with diameters <100 nanometers. Fossil fuel combustion (including natural gas burning) has also been shown to produce more formally recognized types of carbon nanoparticles including carbon nanotubes and fullerenes. Mining and metal refinery operations have recently been shown to generate metal and metal oxide nanoparticles.[5] One particularly damaging aspect of nanoparticle release from combustion reactions or large-scale demolition is that the nanoparticles are often released directly into the air (although mine tailings may also introduce these nanoparticles into natural waters). Airborne nanoparticles are a source of special environmental health concerns for two reasons: (1) airborne pollutants are difficult to contain and can rapidly spread to other ecosystems (both near and far) and (2) airborne particulate contaminants are being implicated in many pulmonary conditions (including chronic obstructive pulmonary disease, pulmonary inflammation, and pulmonary fibrosis), because their unique size makes it easy for them to pass deep into lung tissue, where they may cause severe respiratory irritation.



Pathways by which man-made nanoparticles (NPs) are released into the environment

The other most likely source of nanomaterial contaminants is nanoparticle-enabled consumer products. More than several thousand consumer products, including many items of clothing, personal care products, next-generation batteries, and sporting goods now contain nanomaterials.[6] In the next ten years, nanoparticles will likely be incorporated into many more sophisticated products, including pharmaceuticals and next-generation solar cells or batteries. While the inclusion of nanomaterials in these products can enhance their performance, the breakdown of these products at the end of their useful life also provides several key points of entry for man-made nanoparticles into the environment. When nanoparticles are incorporated into products intended for domestic use (like anti-microbial fabrics or UV-blocking clothing), nanoparticles can end up in landfills or washed down the drain when clothes have been laundered. Nanoparticles that end up in drain water or in landfills can then enter the environment by many different routes.

Once nanoparticles have been disposed of in household garbage or down the drain, their journey through the environment is just beginning. Nanoparticles that escape with water down the drain will eventually enter a wastewater treatment facility. Here, nanoparticle-contaminated water will undergo several purification processes, including mechanical filtering and settling treatments (designed to remove large particles [larger than a grain of sand]), followed by digestion with microbes, and ultimately chemical disinfection. Unfortunately, none of these treatment stages are specifically designed to eliminate nanoparticles from the waste stream. As a result, following waste water treatment, nanoparticles may remain in the purified water that is released back into the environment, or nanoparticles may remain trapped in the microbe-bearing sludge left over from the purification process. Often, the bio-sludge left over from wastewater purification is repurposed as fertilizer for farm land, which can potentially allow man-made nanoparticles to enter soils or small rivers. Alternatively, when nanoparticle-enabled products end up in a landfill, the original product can break down, allowing man-made nanoparticles to leach into soil in and around the landfill area, providing a route for man-made nanomaterials to enter new environments via soils or even ground water sources.



Going outside for a long run? You might choose to grab your favorite UV-blocking shirt. UV resistant, stain-resistant, and antibacterial clothing may all contain nanoparticles. Every time you wash the clothes, some of the nanoparticles can break free and enter the waste water stream. Image sources: (Left) Jules [Julianne] Major from the personal collection of Keith Lohse, (Middle) 2, (Right) 3.

To wrap up, let's take a look at an example of how man-made nanoparticles can be released into the environment when you use a common nanoparticle-enabled consumer product- a UV-blocking running shirt with titanium dioxide (or zinc oxide) nanoparticles incorporated into the fibres.[7] After an invigorating run (or possibly anything from an easy jog to a jaw-dropping parkour workout, it's up to you) you peel off your shirt and drop it into the laundry bin. The shirt has served its purpose. A few days later, into the laundry the shirt goes, then the dryer, and back into your drawer. But the shirt left something behind in the water that went down the drain behind the washing machine- a small amount of titanium dioxide nanoparticles. Ultimately, these nanoparticles end up (with a lot of other unmentionables) in a wastewater treatment facility, where they are filtered, chewed up by microbes, and treated with a small amount of chlorine. Likely, some of the TiO_2 nanoparticles end up in the bio-sludge and some remain in the treated water that is released back into the environment. Once the nanoparticles are released into the environment, they may do harm (as we have seen) to local microbe or plankton populations, depending on the amount of UV light exposure they receive, as well as other factors. There is even a chance that nanoparticles released into soil or surface waters may ultimately end up in drinking water, because drinking water treatment facilities also rely on a series of filtering and disinfection procedures that are not specifically designed to remove nanoparticles from water.

We now know a little bit about how nanoparticle contaminants may escape into the environment. Unfortunately, we still know far less about the specific environmental or human health hazards that some man-made nanoparticles may pose. Understanding the health implications of man-made nanoparticles is just one of many challenges still remaining if we want to understand the environmental behavior of these nanoparticles in great detail. For instance, we don't understand how the various components of a given environment (like available ions, minerals, local bacteria, and organic matter) may interact with different nanoparticles to change their size, shape, composition, and bioavailability. Furthermore, we are still unable to easily detect and monitor man-made nanoparticles that have been released into the environment. As a result, nanoparticles are difficult to track through real ecosystems and many different time-intensive assays are required to even determine whether humans or animals have been exposed to nanoparticles.

Nanotechnology is still a young field. While this means there are many things we still don't know about both the applications and implications of these new materials, this also gives us a new and unique opportunity to develop a chemical industry that could be truly sustainable from its inception. Hopefully, in the near future, we can overcome many of the barriers described above and help nanotechnology grow into a sustainable industry–one in which we can prevent environmental contamination by nanoparticles, rather than just clean up chemical waste after the fact. Look for the next post in this series soon, where we discuss the specific issues of nanoscale titanium dioxide (a very common industrially produced nanoparticle) as an environmental contaminant.

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