

## Nanomedicine Overview

### Background

Nanomedicine is beginning to emerge from research in nanotechnology<sup>1</sup>. Nanotechnologies have features on the scale of nanometers or billionths of a meter. In biology the scale of a single human hair is about 80,000 nanometers wide and a red blood cell is about 7,000 nanometers wide. Materials can be produced that are nanoscale in one dimension (such as ultra-thin surface coatings), in two dimensions (for example, nanotubes and nanowires), or in all three dimensions (nanoparticles and Buckyballs).<sup>2</sup> Nanoscale materials often have novel properties related to their high ratio of surface area and quantum effects.

Worldwide government investment in nanotechnology research has increased more than ten-fold in the last six years from \$432 million in 1997 to an estimated \$4.6 billion in 2004.<sup>3</sup> Most of this funding has been directed to very basic research that could be used in a variety of fields, including nanomedicine. In the U.S., the National Science Foundation is the leading funding source with \$249 million granted in 2004. The National Institutes of Health is a distant fourth with \$70 million in funds granted in 2004.<sup>4</sup> It is estimated that companies will invest \$3.8 billion in nanotech R&D globally in 2004, and that this might be the last year that governments outspend the private sector.<sup>5</sup>

### Current Areas of Nanomedicine Development

Nanomedicine has a limited number of current applications.<sup>6</sup> However, there is evidence that academic findings and industry implementation is at hand. For example, Wyeth and Merck utilize nanocrystal technology in drug formulation research, and Pfizer, GSK, Astra Zeneca and Genentech use quantum dot particles to perform drug screening analysis.<sup>7</sup> Academic centers including Cal Tech and Harvard are using nanowires to create biosensors capable of identifying proteins in cells as well as viruses in the hopes of developing a new generation of diagnostics.<sup>8</sup> Current research and development efforts are concentrated in six primary categories:

- *Antimicrobial Properties.* Efforts are focused on investigating nanomaterials with strong antimicrobial properties. Nanocrystalline silver, for example, is already being used for wound treatment.
- *Biopharmaceutics.* Efforts are focused on drug delivery applications using nanomaterial coatings to encapsulate drugs and to serve as functional carriers. Nanomaterial encapsulation could improve the diffusion, degradation, and targeting of a drug. Furthermore, nanomaterials could serve as camouflage to avoid immune responses, or as agents which could catalyze or respond to certain molecules or chemical events.
- *Implantable Materials.* Efforts are centered on using nanomaterials to repair and replace damaged or diseased tissues. Nanomaterial implant coatings could increase the adhesion, durability, and lifespan of implants, and nanostructure scaffolds could provide a framework for improved tissue regeneration. Moreover,

nanomaterial implants could be engineered for biocompatibility with the host environment to minimize side effects and the risk of rejection. Furthermore, smart nanomaterials could detect and respond to environmental conditions and chemical reactions.

- *Implantable Devices.* Efforts are concentrated on implanting small devices to serve as sensors, fluid injection systems, drug dispensers, pumps and reservoirs, and aids to restore vision and hearing functions. Devices with nanoscale components could monitor environmental conditions, detect specific properties, and deliver appropriate physical, chemical, or pharmaceutical responses. In the longer term, the development of nanoelectronic systems that can detect and process information could lead to nanodevices that serve as retina implants by acting as photoreceptors, and cochlear implants by improving nerve stimulation.
- *Diagnostic Tools.* Efforts are directed at utilizing lab-on-a-chip devices to perform DNA analysis and drug discovery research by reducing the required sample sizes and accelerating the chemical reaction process.<sup>9</sup> Moreover, imaging technologies such as nanoparticle probes and miniature imaging devices could promote early detection and diagnosis of disease.
- *Understanding Basic Life Processes.* Efforts are focused on using nanoscale devices and materials to learn more about how biological systems self-assemble, self-regulate, and self-destroy at the molecular level.<sup>10</sup> Insights into basic life processes will overlap multiple disciplines and could yield scientific breakthroughs.

## Expectations for Nanomedicine

In the short term most experts anticipate a valuable set of research tools and clinically helpful devices will emerge. The Asia-Pacific Economic Cooperation (APEC) Center for Technology Foresight predicts the development of selective nanosensors and drug delivery systems over the next 3 years, and the application of advanced medical diagnostics and the ability to target human cells for organ repair by 2013.<sup>11</sup> The National Nanotechnology Initiative expects new commercial applications in the pharmaceutical industry in the next 2-5 years to include “advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels, and medical diagnostic tools, such as cancer tagging mechanisms.”<sup>12</sup> Leroy Hood predicts it will take 5-8 years to develop the microfluidic nanolabs that will be capable of measuring key interactions within individual cells and aggregating those measurements for hundreds of thousands of cells.

The range of long-term expectations in nanomedicine expands from more cautious forecasts into a realm some scientists view as science fiction. Nanomedicine could potentially overthrow traditional notions about disease and health to usher in a form of medicine based on prediction and prevention instead of treatment.<sup>13</sup> If the wild card breakthrough occurs to the more radical micro-machine form of nanotechnology, it would arguably be the largest single development in the history of technology. An Interagency Working Group on Nano Science, Engineering and Technology recently estimated that the social impact of this development would “...be greater than the combined influences

that the silicon integrated circuit, medical imaging, computer-aided engineering, and man-made polymers have had in this century “ Speculations about the medical devices that might become possible range from cell herding machines that could supplement the body’s own tissue repair mechanisms, to cell repair machines that could kill viruses that attach to genetic material within cells and repair cellular damage caused by disease, chemicals or radiation. Genetic surgery might become a simple procedure done by swallowing a tiny pill. Ultimately, we might be able to counter or repair many of the effects of aging. While possibilities like these are highly controversial and uncertain, they suggest that nanomedicine today is still in a primitive state compared to what may be possible in the long run.

## Questions About Nanomedicine

Where is nanomedicine most likely to develop over the next 5 years?

What nanomedicine applications will transfer most rapidly from the research setting to clinical medicine?

Which potential contributions from nanomedicine would improve health most by 2029 and which would be most dangerous to health?

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<sup>1</sup> As evidence see the announcement for a new journal devoted to Nanomedicine [http://www.kurzweilai.net/news/frame.html?main=/news/news\\_single.html?id%3D4166](http://www.kurzweilai.net/news/frame.html?main=/news/news_single.html?id%3D4166).

<sup>2</sup> The Royal Society. (July, 2004) “Nanoscience and Nanotechnologies: Opportunities and Uncertainties.” Accessed online at: <http://www.royalsoc.ac.uk>

<sup>3</sup> Roco, M.C. (June 30, 2003) “Government Nanotechnology Funding: An International Outlook.” National Science Foundation. Accessed online at: <http://www.nano.gov/html/res/IntlFundingRoco.htm>

<sup>4</sup> Roco, M.C. (June 30, 2003) “Government Nanotechnology Funding: An International Outlook” National Science Foundation. Accessed online at: <http://www.nano.gov/html/res/IntlFundingRoco.htm>

<sup>5</sup> Kanellos, Michael. (2004, August 16) “Nanotech funding to grow to \$8.6 billion,” TechRepublic.com. Accessed online at: [http://techrepublic.com.com/5100-22\\_11-5311278.html?part=rss&tag=feed&subj=tr](http://techrepublic.com.com/5100-22_11-5311278.html?part=rss&tag=feed&subj=tr)

<sup>6</sup> “Applications/Products” National Nanotechnology Initiative. Accessed online at <http://www.nano.gov/html/facts/appsprod.html>

<sup>7</sup> “Nanotechnology – Product News.” Country Doctor. July 19, 2004. Accessed online at <http://www.countrydoctor.co.uk/education/education%20-%20Nanotechnology.htm>

<sup>8</sup> See [http://www.systemsbiology.org/extra/PressRelease\\_102204.html](http://www.systemsbiology.org/extra/PressRelease_102204.html) and also <http://cmliris.harvard.edu/research/devices/index.php>.

<sup>9</sup> “Nanotechnology Enabling Lab-on-a-Chip Devices.” Institute of Nanotechnology. Accessed online at <http://www.azonano.com/details.asp?ArticleID=886>

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<sup>10</sup> Tegart, Greg. "Nanotechnology: The Technology for the 21<sup>st</sup> Century." The APEC Center for Technology Foresight. Bangkok, Thailand. Presented at The Second International Conference on Technology Foresight, Tokyo, Feb. 27-28, 2003.

<sup>11</sup> Tegart, Greg. "Nanotechnology: The Technology for the 21<sup>st</sup> Century." The APEC Center for Technology Foresight. Bangkok, Thailand. Presented at The Second International Conference on Technology Foresight, Tokyo, Feb. 27-28, 2003.

<sup>12</sup> "Applications/Products" National Nanotechnology Initiative. Accessed online at <http://www.nano.gov/html/facts/faqs.html>

<sup>13</sup> "Emerging nanomedicine technologies could dramatically transform medical science" News-Medical.net. July 23, 2004. Accessed online at <http://www.news-medical.net/?id=3543>