Content Unit

The Future of Nano

Name of author: Nikolina Latković
Last processing date: 20.12.2021

The Future of Nano

First introduction

Nanotechnology is a highly innovative field. There are so many possibilities when it comes to the future of nano. However, the future is not without its challenges. Nano can help us resolve the issues of tomorrow. We will have a look at the specific applications of nano in agriculture and food, medicine as well as what the cities of the future will look like thanks to nano.

Practical relevance – This is what you will need the knowledge and skills for

In this unit, you will learn how nano will improve the food and agriculture sector as well as medicine. Finally, you will learn how nano will transform the cities of tomorrow.

Overview of learning objectives and competences

In *The future of agriculture and food*, you will learn how nano will change the food industry, the growing role of nano in agriculture and finally how nano will improve the agriculture of the future.

In *The future of nanomedicine*, you will learn how nano will enable better health monitoring by scaling down health tech, help in the fight against cancer and the promise of incredible innovations.

In *The future of our cities*, you will learn how nano will supply energy for our cities in the future as well as how it transformss our cities' infrastructures. Finally, you will learn how nano will enable sensors and computers to monitor and process data to insure the safety of our cities in the future.

Learning objectives	**Fine objectives**
LG_BB_01 The future of agriculture and food	FO_The future of nano 01_01 The future food industry FO_ The future of nano 01_02 Nano in agriculture FO_ The future of nano 01_03 The future of our agriculture
LG_BB_02 The future of nanomedicine	FO_ The future of nano 02_01Scaling down health tech

	FO_The future of nano 02_02 Nanomedicine against cancer FO_ The future of nano _02_03 Incredible innovations
LG_BB_03 The future of our cities	FO_ The future of nano 03_01 Supplying energy for the cities of the future FO_ The future of nano 03_02 The future infrastructures of our cities FO_ The future of nano _03_03 The safety of our cities in the future

1.The future of agriculture and food

The European Commission considers nanotechnology a key enabling technology with great potential for addressing the societal issues of the future such as energy supply and health care (European Commission, 2021).

However, nanotechnology has also become progressively important in the food industry. Food innovation is observed as one of the sector areas in which nanotechnology will play a major part in the future. New and future innovations is nanotechnology have exceptionally extraordinary property various areas of the food industry and agriculture sector all around the world (Thiruvengadam *et a*l., 2018). These include:

- precision farming techniques
- smart feed
- enhancement of food texture and quality
- bioavailability/nutrient values
- packaging
- labeling
- crop production
- use of agrochemicals such as nano-pesticide
- nano-fertilizers
- nano-herbicide

As well, nanofood packaging resources may widen nourishment life, upgrade food safety, inform customers that food is sullied or destroyed, repair tears in packaging, and uniformly release added substances to extend the life of the food in the package (Thiruvengadam *et a*l., 2018).

Remember
Nano and food innovation Food innovation is observed as one of the sector areas in which nanotechnology will play a major part in the future

To maintain leadership in food and food-processing industry, one will have to work with nanotechnology in the future. Improving the safety and quality of food will be the first step. Engineered nanotech compounds could offer great benefits in ingredients as well as in food packaging — with antimicrobial surfaces and sensors that change color when food begins to degrade (Thiruvengadam *et a*l., 2018).

Some people might be worried about nano in their food, but nanoscale compounds already exist naturally in milk and are responsible for its fat stability. Moreover, nano is already widely used in the food packaging sector to help ensure food quality and safety. Nanotech-based sensors can detect and measure the presence of oxygen or bacteria, such as listeria (MacDonald, 2017).

“Nanotechnology enables to change the existing food systems and processing to ensure products safety, creating a healthy food culture, and enhancing the nutritional quality of food” (Thiruvengadam *et al*., 2018).

Regarding agriculture, nanoparticles are already used in the field (no pun intended) to enhance production. For instance, polymeric nanoparticles are used in the delivery of agrochemicals in a slow and controlled manner. Some of the advantages of polymeric nanoparticles are their superior biocompatibility and minimal impact on non-targeted organisms (Bose, 2021).

As well, silver nanoparticles are extensively used for their antimicrobial property against a wide range of phytopathogens (an organism that causes disease in plants). Scientists have also reported that silver nanoparticles enhance plant growth. Many chemical companies also use nano alumino-silicate formulations as an efficient pesticide. Meanwhile, titanium dioxide nanoparticles are biocompatible and are used as a disinfecting agent for water. On the other hand, carbon nanoparticles such as graphene, graphene oxide, carbon dots, and fullerenes, are used for improved seed germination (Bose, 2021).

Definition
Phytopathogen An organism that causes disease in plants.

The application of nanoherbicides and nanopesticides for the management of weed and pests have significantly increased crop productivity. Huge agricultural losses are incurred annually owing to microbial (virus, fungus, and bacteria) infections. Nanomaterials with specific antimicrobial properties can help prevent those microbial

infestations. Several nanoparticles such as nickel ferrite nanoparticles and copper nanoparticles, have a strong antifungal property and are effectively used in disease management (Bose, 2021).

Nanotechnology was also used to design a smart delivery system that would release nutrients in a slow and controlled manner to the targeted site to tackle nutrient deficiency in plants. Nanofertilizers increase crop productivity by enhancing the availability of essential nutrients to the plant. A significant increase in the yields of millet and cluster beans was found after the application of nanophosphorus fertilizers in arid conditions. Chitosan nanoparticles suspensions containing nitrogen, phosphorus, and sodium have also increased crop production (Bose, 2021).

As well, carbon nanotubes can enter the hard seed coat of tomatoes and significantly improve the germination index and plant growth. Similarly, the germination percentage increased when soybean and corn seeds were sprayed with multiwall carbon nanotubes. Various nano treatments are available to enhance the germination index of plants. (Bose, 2021).

Finally, nanobiosensors are highly sensitive and specific when compared to conventional biosensors. These devices convert biological responses to electrical responses via a microprocessor. Nanobiosensors offer a real-time signal monitoring and are involved in direct or indirect detection of pathogenic microorganisms, antibiotic resistance, pesticides, toxin, and heavy metal contaminants. This technology is also used to monitor crop stress, soil health, plant growth, nutrient content, and food quality (Bose, 2021).

However, this is only the beginning of nano in agriculture. We expect that in the future nanotechnology will help us with:

- Controlled green synthesis of nanoparticles
- Understanding of nanoparticles produced by root endophytes and mycorrhizal fungi, which play an important role in plant productivity and disease management
- Interaction of nanoparticles with plant system such as transport mechanism of nanoparticles inside plant body
- Critical evaluation of the negative side effects of nanoparticles on different environmental conditions
- Development of portable and user-friendly nanobiosensors for rapid analysis of soil, plants, water, and pesticides

Definition
Green synthesis Green synthesis method involves the development of nontoxic and biocompatible safe nanoparticle production at low cost and with prospective wide-ranging applications in different sectors.

As the global population is increasing and we are facing climate change as well higher demands of energy and water, there will be more stress on food production and distribution.

Nanomaterials and nanotechnology could play an important role in the future of agriculture, especially in the production of crops. “Nano-enabled agriculture is still in its infancy but it is an exciting and challenging area that will develop fast in the near future” (Pulizzi, 2019).

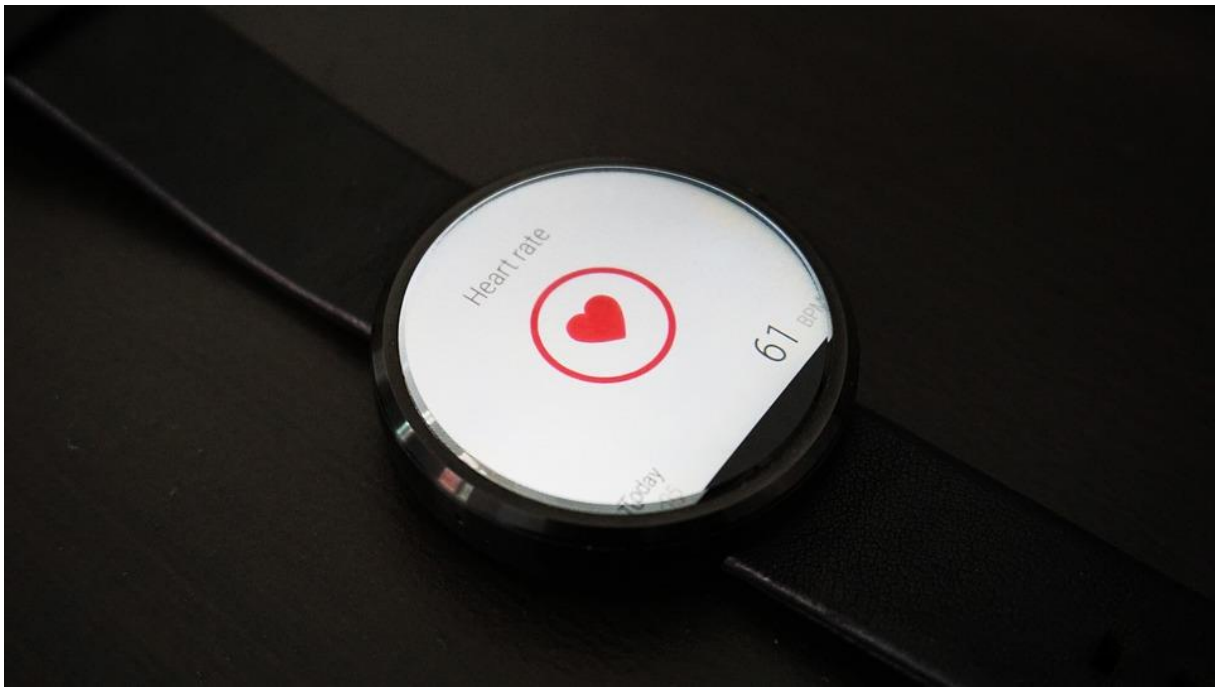
Thus, nanotechnology will help us feed more people more quickly and more efficiently as well bringing innovation in the packaging of our food.

Important
The future of agriculture Nanomaterials and nanotechnology could play an important role in the future of agriculture, especially in the production of crops which will increase food production.

2. The future of nanomedicine

Wearable fitness technology means we can monitor our health by strapping gadgets to ourselves. There are even prototype electronic tattoos that can sense our vital signs. But by scaling down this technology, we could go further by implanting or injecting tiny sensors inside our bodies. This would capture much more detailed information with less hassle to the patient, enabling doctors to personalise their treatment (Prodromakis, 2018).

The possibilities are endless, ranging from monitoring inflammation and post-surgery recovery to more exotic applications whereby electronic devices actually interfere with our body's signals for controlling organ function. Although these technologies might sound like a thing of the far future, multi-billion healthcare firms such as GlaxoSmithKline are already working on ways to develop so-called "electroceuticals" (Prodromakis, 2018).



Remember
Scaling down health and fitness technology The possibilities are endless, ranging from monitoring inflammation and post-surgery recovery to more exotic applications whereby electronic devices actually interfere with our body's signals for controlling organ function

Furthermore, nanotechnology is being studied for both the diagnosis and treatment of atherosclerosis, or the buildup of plaque in arteries. In one technique, researchers created a nanoparticle that mimics the body's "good" cholesterol, known as HDL (high-density lipoprotein), which helps to shrink plaque. The design and engineering of advanced solid-state nanopore materials could allow for the development of novel gene sequencing technologies that enable single-molecule detection at low cost and high speed with minimal sample preparation and instrumentation (NNI, 2021).

Nanotechnology researchers are also working on a number of different therapeutics where a nanoparticle can encapsulate or otherwise help to deliver medication directly to cancer cells and minimize the risk of damage to healthy tissue. For instance, carbon nanotubes are being explored to achieve targeted drug delivery. This has the potential to **change the way doctors treat cancer and dramatically reduce the toxic effects of chemotherapy** (NNI, 2021). Other emerging nanomaterials such as block copolymer micelles, polymers, quantum dots and dendrimers are also designed to help deliver or target drugs more efficiently (EUON, 2021).

For instance, quantum dots are semiconductor nanocrystals that are composed of an inorganic core surrounded by a metallic shell. They can be used as drug carriers or as fluorescent labels for other drug carriers such as liposomes. They can help to combine molecular imaging for diagnostics with therapy, for example, in the development of therapeutic strategies for cancer (EUON, 2021).

Meanwhile, dendrimers are molecules with a regular and highly branched tree-like structure. They measure between 1 and 10 nanometres in diameter and have a hydrophobic internal cavity that can be filled with hydrophobic molecules, for instance, anticancer drugs. Compared to other drug carriers such as liposomes, dendrimers are mechanically more stable but can carry smaller amounts of the drug (EUON, 2021).

Another way nanotechnology can help us in the fight against cancer is with individualized treatments. Indeed, in the future, **nanotechnology may allow us to receive individualised therapeutic treatments**. Newly developed nanomedicines include multi-component systems called theranostics that can, for example, incorporate both therapeutic and diagnostic molecules. The resulting nano-system will allow diagnosis, drug delivery and monitoring of the effects of the medicine. The development of such systems can help to reach the goal of obtaining individualised therapies for multiple diseases. The reason behind the increasing amount of research done in the direction of personalised nanomedicine is that diseases such as cancer are extremely heterogeneous and the existing treatments are effective only for certain patients and at a certain stage of the disease. The administration of a theranostic agent to a patient can potentially allow monitoring of how well the patient responds to the nanomedicine, as the imaging molecules enable the real-time visualisation of the effect of the

drug. As a result, drug dosage and treatment protocols can be optimised and individualised during follow-up (EUON, 2021).

As well, research in the use of nanotechnology for regenerative medicine spans several application areas, including bone and neural tissue engineering. For instance, novel materials can be engineered to mimic the crystal mineral structure of human bone or used as a restorative resin for dental applications. **Researchers are looking for ways to grow complex tissues with the goal of one day growing human organs for transplant**. Researchers are also studying ways to use graphene nanoribbons to help repair spinal cord injuries; preliminary research shows that neurons grow well on the conductive graphene surface (NNI, 2021).

Finally, nanomedicine researchers are looking at ways that nanotechnology can improve vaccines, including vaccine delivery without the use of needles. Researchers also are working to create **a universal vaccine scaffold for the annual flu vaccine that would cover more strains and require fewer resources to develop each year** (NNI, 2021).

Thus, nanomedicine will enable better health monitoring by scaling down health tech meanwhile emerging nanomaterials will provide targeted drug delivery and individualized treatments which will help in the fight against several diseases including cancer. Finally, nanomedicine offers the promise of incredible innovations such as growing human organs for transplant and the creation of a universal vaccine scaffold for the annual flu vaccine.

Remember
Nanomedicine against cancer Nanotechnology researchers are working on a number of different therapeutics where a nanoparticle can encapsulate or otherwise help to deliver medication directly to cancer cells and minimize the risk of damage to healthy tissue. This has the potential to change the way doctors treat cancer and dramatically reduce the toxic effects of chemotherapy.

3. The future of our cities

The fight against climate change means we need new ways to generate and use electricity, and nanotechnology is already playing a role. The common denominator of the big challenges facing humanity for the next 50 years

is energy as fossil fuels production has already peaked and we are looking at alternative sources of energy. (Williams & Adams, 2017). One of the challenges is energy storage. Nano has helped create batteries that can store more energy for electric cars and has enabled solar panels to convert more sunlight into electricity. The common trick in both applications is to use nanotexturing or nanomaterials (such as nanowires or carbon nanotubes) that turn a flat surface into a three-dimensional one with a much greater surface area. This means that there is more space for the reactions that enable energy storage or generation to take place. Thus, the devices operate more efficiently. In the future, nanotechnology could also enable objects to harvest energy from their environment. New nano-materials and concepts are currently being developed that show potential for producing energy from movement, light, variations in temperature, glucose and other sources with high conversion efficiency (Prodromaki, 2018).

Furthermore, wires containing carbon nanotubes are being developed that will have much lower resistance than the high-tension wires currently used in the electric grid, thus reducing transmission power loss. Similarly, various nanoscience-based options are being pursued to convert waste heat in computers, automobiles, homes, power plants, etc., to usable electrical power (NNI, 2018).

Nanotechnology can also be incorporated into solar panels to convert sunlight to electricity more efficiently, promising inexpensive solar power in the future. Nanostructured solar cells could be cheaper to manufacture and easier to install, since they can use print-like manufacturing processes and can be made in flexible rolls rather than discrete panels. Newer research suggests that future solar converters might even be “paintable.” (NNI, 2018).

Nanotechnology will also impact the future infrastructures of our cities. Nano-engineering of aluminum, steel, asphalt, concrete and other cementitious materials, and their recycled forms offers great promise in terms of improving the performance, resiliency, and longevity of highway and transportation infrastructure components while reducing their life cycle cost. New systems may incorporate innovative capabilities into traditional infrastructure materials, such as **self-repairing structures** or the ability to generate or transmit energy (NNI, 2018).

As well, **nanocoatings or nanoadditives will even have the potential to allow materials to "heal" when damaged or worn.** For example, dispersing nanoparticles throughout a material means that they can migrate to fill in any cracks that appear. This could produce self-healing materials for everything from aircraft cockpits to microelectronics, preventing small fractures from turning into large, more problematic cracks (NNI, 2018).

Nanostructured optics allow for production of light sources with extended abilities in directing the light cone, thus significantly improving the efficiency and reducing the cost of energy. Lamps using nanooptics direct light only to the areas where it is needed. The possibility to precisely control every ray of light emitted by the source will allow for significant reduction of light pollution in cities in the future.

Nanoscale sensors and devices may provide cost-effective continuous monitoring of the structural integrity and performance of bridges, tunnels, rails, parking structures, and pavements over time. **Nanoscale sensors, communications devices, and other innovations enabled by nanoelectronics can also support an enhanced transportation infrastructure that can communicate with vehicle-based systems to help drivers maintain lane position, avoid collisions, adjust travel routes to avoid congestion, and improve drivers' interfaces to onboard electronics** (Prodromakis, 2018). Thus, nanotechnology offers the promise of developing multifunctional materials that will contribute to building and maintaining lighter, safer, smarter, and more efficient vehicles, aircraft, spacecraft, and ships. In addition, nanotechnology offers various means to improve the transportation infrastructure (NNI, 2018).

Remember

The future is self-repairing structures

Nanocoatings or nanoadditives will even have the potential to allow materials to "heal" when damaged or worn.

These nanoscale sensors rely on newly invented nanomaterials and manufacturing techniques to make them smaller, more complex and more energy efficient. For example, sensors with very fine features can now be printed in large quantities on flexible rolls of plastic at low cost. This opens up the possibility of placing sensors at lots of points over critical infrastructure to constantly check that everything is running correctly. Bridges, aircraft and even nuclear power plants could benefit (Prodromakis, 2018).

However, all these sensors will produce more information than we've ever had to deal with before – so we'll need the technology to process it and spot the patterns that will alert us to problems. **The same will be true if we want to use the big data from traffic sensors to help manage congestion and prevent accidents, or prevent crime by using statistics to more effectively allocate police resources** (Prodromakis, 2018).

Here, nanotechnology is helping to create ultra-dense memory that will allow us to store this wealth of data. But it's also providing the inspiration for ultra-efficient algorithms for processing, encrypting and communicating data without compromising its reliability. Nature has several examples of big-data processes efficiently being performed in real-time by tiny structures, such as the parts of the eye and ear that turn external signals into information for the brain. Computer architectures inspired by the brain could also use energy more efficiently and therefore would struggle less with excess heat – one of the key problems with shrinking electronic devices further (Prodromakis, 2018).

As well, the use of nanotechnology-enabled lightweight, high-strength materials would apply to almost any transportation vehicle. For example, it has been estimated that **reducing the weight of a commercial jet aircraft by 20 percent could reduce its fuel consumption by as much as 15 percent**. A preliminary analysis performed for **NASA has indicated that the development and use of advanced nanomaterials with twice the strength of conventional composites would reduce the gross weight of a launch vehicle by as much as 63 percent**. Not only could this save a significant amount of energy needed to launch spacecraft into orbit, but it would also enable the development of single stage to orbit launch vehicles, further reducing launch costs, increasing mission reliability, and opening the door to alternative propulsion concepts (NNI, 2018)

Remember

The future is in space

NASA has indicated that the development and use of advanced nanomaterials with twice the strength of conventional composites would reduce the gross weight of a launch vehicle by as much as 63 percent**.** Not only could this save a significant amount of energy needed to launch spacecraft into orbit, but it would also enable the development of single stage to orbit launch vehicles, further reducing launch costs, increasing mission reliability, and opening the door to alternative propulsion concepts

Finally, researchers are investigating carbon nanotube “scrubbers” and membranes to separate carbon dioxide from power plant exhaust. As well, they are developing wires containing carbon nanotubes that will have much lower resistance than the high-tension wires currently used in the electric grid, thus reducing transmission power loss (NNI, 2018).

In brief, in the future, nano will transform our cities to insure renewable energy supply as well as storage. Nano will introduce self-repairing structures and nanoscale sensors to monitor all the vital infrastructures that run our cities such as highways, bridges and powerplants. As well, nano will provide means to store and process data provided by the sensors to ensure the safety of our infrastructures and our citizens. Finally, nanotechnology-enabled lightweight and high-strength materials will make reaching the stars a bit easier while nanotubes scrubbers and membranes will give us cleaner air.

Remember
The future is clean air Researchers are investigating carbon nanotube “scrubbers” and membranes to separate carbon dioxide from power plant exhaust

1.Save knowledge

Summary

You reached the end of the content unit 'The Future of Nano'. As there was a lot to learn, please check out this quick summary of the most important things you learned about this topic:

As the global population is increasing and we are facing climate change as well higher demands of energy and water, there will be more stress on food production and distribution. Nanomaterials and nanotechnology could play an important role in the future of agriculture, especially in the production of crops. "Nano-enabled agriculture is still in its infancy, but it is an exciting and challenging area that will develop fast in the near future" (Pulizzi, 2019). Thus, nanotechnology will help us feed more people more quickly and more efficiently as well as bringing innovation in the packaging of our food.

Nanomedicine will enable better health monitoring by scaling down health tech meanwhile emerging nanomaterials will provide targeted drug delivery and individualized treatments which will help in the fight against several diseases including cancer. Finally, nanomedicine offers the promise of incredible innovations such as growing human organs for transplant and the creation of a universal vaccine scaffold for the annual flu vaccine.

Nanotechnology will transform our cities to insure renewable energy supply as well as storage. Nano will introduce self-repairing structures and nanoscale sensors to monitor all the vital infrastructures that run our cities such as highways, bridges and powerplants. As well, nano will provide means to store and process data provided by the sensors to ensure the safety of our infrastructures and citizens. Finally, nanotechnology-enabled lightweight and high-strength materials will make reaching the stars a bit easier while nanotubes scrubbers and membranes will give us cleaner air.

References

- Bose, D. (2021). How Agricultural Nanotechnology Will Influence the Future of Farming Sustainability. Retrieved from : https://www.azonano.com/article.aspx?ArticleID=5647
- EUON (2021). Future of nanomedicines. Retrieved from: https://euon.echa.europa.eu/future-of-nanomedicines
- European Commission (2021). Nanotechnology. Retrieved from : https://ec.europa.eu/jrc/en/research-topic/nanotechnology
- MacDonald, C. (2017) What is the future of nanotechnology in food. Retrieved from: https://www.fooddive.com/news/what-is-the-future-of-nanotechnology-in-food/446173/
- National Nanotechnology Initiative (NNI). (2021) Applications of nanotechnology. Retrieved from: https://www.nano.gov/about-nanotechnology/applications-nanotechnology
- Prodromakis, T. (2018) Five ways nanotechnology is securing your future. Retrieved from: https://phys.org/news/2016-03-ways-nanotechnology-future.html
- Pulizzi, F. Nano in the future of crops. *Nat. Nanotechnol.* **14,** 507 (2019). https://doi.org/10.1038/s41565-019-0475-1
- Rahman, T. (2020). The future of nanotechnology. Retrieved from: https://medium.com/predict/the-future-of-nanotechnology-accddc9822fb
- Thiruvengadam, M., Rajakumar, G., & Chung, I. M. (2018). Nanotechnology: current uses and future applications in the food industry. *3 Biotech*, *8*(1), 74. https://doi.org/10.1007/s13205-018-1104-7
- Williams L. and Adams W. (2017) Nanotechnology Demystified. McGrawHill, 343 pages.