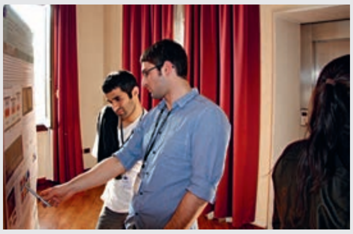
Global Challenges

Opportunities for Nanotechnology



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Introduction

Nanotechnology, one of the most thriving key technologies of this century, is generally expected to play a leading role in the development of solutions for our global challenges. Raising awareness of these emerging challenges, particularly amongst the future generation of scientists, seems essential for the development of successful solution strategies.

Since these global challenges will require concerted efforts on an international level, a tightly interacting network must be formed amongst the future generation of scientists. To this end a lively group of PhD students and postdocs from all over the world, working in different fields of nanoscience gathered at the Venice International University on San Servolo for a concise and focused workshop to discuss these challenges as research opportunities, and to initiate a network amongst those scientists who will shape our scientific and technological future.

CHALLENGES FOR THE NEXT GENERATION OF SCIENTISTS

Between April 15th and 18th, 2013, the Center for NanoScience Munich, the Swiss Nanoscience Institute Basel and the ETH Zürich organized a workshop with the aim of raising the next generation of nanoscientists' awareness of the global challenges looming on the horizon. Postdocs and senior PhD students from a broad range of countries from all continents were invited with the goal of initiating a global network. The meeting eventually gathered 57 participants with 28 nationalities from all continents. Their scientific backgrounds, though nanoscience-oriented, ranged from physics and chemistry to life sciences and also included engineering and IT disciplines. With 18 female participants, the gender balance mirrored those of the disciplines involved. Particular emphasis was placed on inviting students from developing and threshold countries, as well as on ethnic and gender balance. Unfortunately, not all of the students were able to accept the invitation due to visa problems and other hurdles.

This workshop was the follow-up to a previous workshop entitled "Global challenges – how can nanotechnology help?" held in the same location in 2008. Since then marked changes in the global system, such as the Arab spring, the world economic crisis, the nuclear accident in Fukushima, the oil spill in the Gulf of Mexico and other environmental disasters, had altered the global balance, so it seemed necessary, timely and appropriate to revisit this topic five years on. The title was altered slightly to take into account that a perception of global challenges as opportunities counteracts the tendency to demonize changes and at the same time motivates those that are willing to deal with these demanding and highly entangled topics.

Following suggestions from the participants of the previous workshop, a small team of experts was added to support the discussions. Two Nobel laureates, Jean-Marie Lehn and Gerd Binnig, Viola Vogel (the former US presidential nanotechnology advisor) and Adi Scheidemann, a nanotechnology entrepreneur, brought their detailed knowledge and know-how to the discussions.

The workshop was motivated by three major goals:

- **Identification of global challenges viewed from the student's perspective**
  From the gofer's perspective of the lab to the eagle's view of the world!

- **Focusing on those topics where nanoscience may contribute to solutions**
  Convergence with other technologies with the goal of developing high-tech solutions as well as sustainable low-key technologies.

- **Initiation of a global junior nanoscientists' network**
  Direct personal contacts enable possible joint projects which otherwise might be stuck in the mud-holes of bureaucracy.

HOW TO ADDRESS THESE CHALLENGES? – STRUCTURE OF THE WORKSHOP

What is your expertise?

In the first part of the meeting all participants introduced themselves in 3-minute talks and with poster presentations in the subsequent poster session. The presented topics were as diverse as the participants' backgrounds: From energy transfer with quantum dots, acoustic biosensors for point-of care diagnosis and plasmonic nanostructures to synthetic genetic molecules.

Identify global challenges

For the second block, a less traditional format was applied. First, global challenges were collected and discussed in two rounds of roundtable discussions in six subgroups. A "wisdom keeper" kept the ideas discussed at a specific table and passed them from round to round while the participants mixed anew at the tables. The discussion groups then defined criteria to assess the proposed challenges and narrowed them down to a concise list. Finally, the group decided to focus the discussions on those problems where nanotechnology promises to become instrumental, well aware that their selection covers only a fraction of the challenges to be addressed by mankind.

How can nano help?

In the third part, the potential of nanoscience to address global challenges was explored in focused discussion groups. The participants split into six groups, each dealing with one of the identified topics. Due to the uneven distribution amongst the different disciplines (biophysics dominated), certain topics like "health" attracted more participants for the discussions than topics like "new materials". The outcome is summarized in → Table 1.

Use your expertise and team up globally

The fourth and last part was deliberately left more or less unstructured. Since the participants had gained an insight into the expertise of the other participants in the first block and had elucidated the scientific potential in greater detail in the following blocks, this last part allowed them to exchange concrete research ideas with their peers and to team up for cooperation projects. Typically two or three partners joined together and came up with brief concepts highlighting the basic principles of their idea which they presented to the group.

Challenges Are Opportunities! –

In the first round of group discussions a broad list of topics was identified where nanosciences are expected to contribute to the solutions. The wordle in → Figure 1 illustrates the challenges listed by the participants in this initial phase. However, the ranking of these topics proved to be very difficult.

CRITERIA FOR GLOBAL CHALLENGES

In order to assess the challenges under discussion, criteria were collected and their relevance was discussed. In a next step, the identified challenges were analyzed using the most relevant criteria in order to establish a ranking of the previously identified global problems. One of the prevailing criteria was found to be the **global impact** of the specific challenge on humankind and on the environment. The **scale of the problem** – whether a large part of the world's population, independent of their economic and demographic condition, is affected – dominated the evaluation of a specific problem. Moreover, the impact of a challenge could also be related to the global and/or local environment. Evidently, the **urgency** of finding solutions played a major role in the rating of existing global challenges and is closely connected with the question of **essentiality**, i.e., whether finding a solution is vital for humankind, and with the **speed of damage** associated with a certain problem. In addition, while the **sustainability** of a solution was considered an important criterion, the **transfer of information**, **time frame** and the **risk** associated with finding a solution were considered to be minor issues compared to the urgent need to find promising opportunities. Other significant considerations are the **ethical-social implications** related to possible solutions, taking into account the need for public acceptance of a new technique in order to successfully introduce it. Furthermore, the **costs** associated with the development of solutions were defined as a major criterion.

While the **feasibility** of a possible problem-solving option in general is evidently of the utmost importance, the **potential for finding a solution based on nanotechnology** was an even more relevant criterion in this workshop owing to the scientific background of the participants. This restriction directly implies that only problems that can be addressed with the help of nanotechnology are included in our list of global challenges. For that reason, issues like the growth of the world population as well as political and religious conflicts are not discussed. Finally, the participants also took into account whether there is a particular **need to act** or if there are already strong and promising research activities going on in a certain field.

The criteria defined above were used to identify six global problems, which were found to be of the highest importance in this nanotechnology-related context (in alphabetical order):

- Energy
- Environment
- Food
- Health
- New Materials
- Water

→ Table 1 provides a summary.

Figure 1: Global Challenges, illustrated as a wordle. The size of a word is proportional to how often it was listed by the participants during the initial discussions.

Analysis and suggestions

Global Challenge	Global Impact	Urgency	Sustainability of a solution	Nanoscience potential	Costs
ENERGY					
◦ Production ◦ Storage ◦ Transport ◦ Consumption	Very high	High	Depends on energy source and consumption	New solar cells, biofuels, photobiosynthesis, new methods for energy storage …	Depend on energy source, storage and transport
ENVIRONMENT					
◦ Climate change (carbon capture & storage) ◦ Pollution and waste ◦ Recycling & reusing ◦ Biodiversity	Very high	High	Yes	Develop smart cycles of energy-producing and plastic-degrading organisms; new approaches for exhaust purification and removal of unwanted chemicals …	To be seen in relation with indirect costs caused by waste, pollution or climate change
FOOD					
◦ Availability ◦ Preservation & distribution ◦ Sourcing ◦ Substitutes & supplements ◦ Recycling	Mainly for developing countries, indirect effects from developed countries	High in certain areas	Depends on production methods	Soil supplements to enable crop growth in hostile environments; basic food resource; artificial meat	Depend
HEALTH					
◦ Diagnosis ◦ Prevention ◦ Therapy	Very high, focus might vary regionally	Very high	Depends on disease and treatment	Drug delivery, sensors for point-of-care diagnostics, improvement of vaccine production, tissue design …	Reduction possible by early diagnosis, prevention measures and new drugs
NEW MATERIALS					
◦ Specific properties ◦ Resource/energy saving production ◦ Intelligent	Depends on area of application	Depends	Depends on material	Energy-saving materials, new anti-microbial materials, self-healing, self-cleaning, shape-memory materials …	Potential for cost reduction
WATER					
◦ Availability ◦ Purification ◦ Infrastructure	Mainly for developing countries	High in certain areas	Depends on method	Nano-encapsulation for purification	Depend on technique

Table 1: Global challenges and criteria for their evaluation.

Energy

Energy was a central topic of discussion for all participants. Since many of the other challenges are directly or indirectly affected by the availability of energy, e.g., purification and desalination of water, this topic received the most attention. Global challenges concerning energy comprise the following aspects:

- Energy production
- Energy storage
- Energy infrastructure
- Energy transport efficiency

Nanotechnology develops new and optimizes old processes on the microscale (see → **Figure 2**) that push efficiency on the macroscale. In the face of global climate change, new sources of energy are needed to bridge our transition away from fossil fuels and to provide enough power for an exponentially growing world population. Currently, fossil fuels are the most widely used and portable energy source, but their availability is limited. Alternative energy sources include light, harvested by solar cells, and biofuels.

Solar cells still exhibit limitations regarding lifetime and stability, preparation costs and upscaling, and fundamentally, weather dependence. In addition, the use of scarce elements (indium etc.) for the production of solar cells is critical. Last but not least, only a certain spectral part of light is currently used for energy conversion.

Biofuels are ideally produced from biological waste or from engineered organisms. With genetically engineered microorganisms, processing abundant organic waste into fuel, a breakthrough might be close, especially considering their seamless fit into our existing, liquid fuel-based transportation system. Ideally, their production and consumption should be a carbon neutral process.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR ENERGY PRODUCTION:

Solar Cells

Nanoscience can contribute significantly to the development of new solar cells by designing new conductive polymers, by methods of nanostructuring, and by improving their scale-invariance (from calculators to city roofs). Different types of light-harvesting systems were discussed:

- **Quantum dot-based solar cells** provide higher theoretical efficiencies for photovoltaics, but are currently limited by lifetime and overall efficiency. Nanoscience can contribute here by pursuing early-stage research for fundamental understanding.

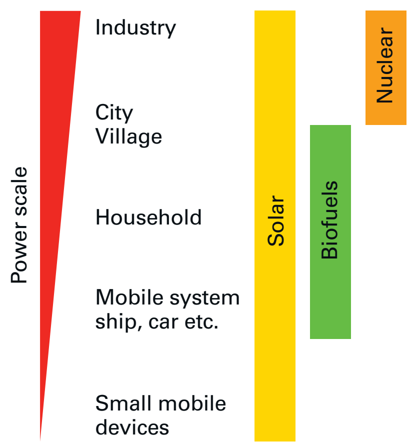


Figure 2: As the power required to supply the systems listed on the left rises, different technologies (matched on the right) apply. The scaling of an energy source is of key importance in deciding its application.

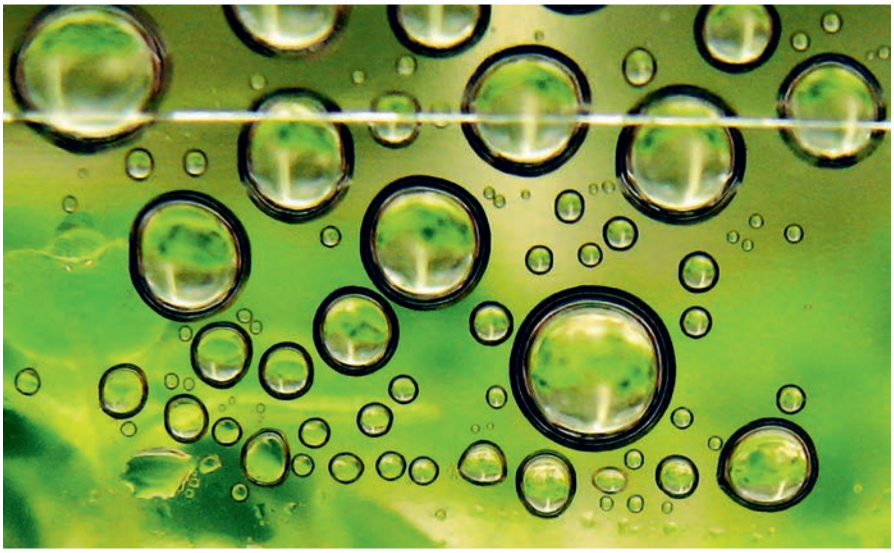
- The key advantage of **thin film applications** in solar cells is to minimize material usage for solar cell production. Challenges are production cost and upscaling processes. Nano research opportunities can be found in nanostructuring and material design, as well as in the development of bulk methods for thin film deposition.

- **Dye-sensitized solar cells (DSSC)** are a very promising approach for conversion of light energy. Advantages of this method are low production costs, usage of diffuse light and environmentally-friendly production compared to conventional solar cells; however, durability and stability of the cells is still an issue. Research could focus on upscaling possibilities and on solid-state devices.

- **Photobiosynthesis** aims to use nature's methods of light energy conversion (photosystem I and II in plants). The challenges in this research area are harvesting the electrons, connecting a photosystem to the electrode via a biological-inorganic interface, and developing efficient methods for protein nanoscale arrangement. Further research is needed here to elucidate the underlying processes and to make the progress in protein engineering necessary for this kind of application.

Biofuels

A major obstacle for the conversion of biomass into biofuels is the inefficient breakdown of lignocellulose-containing biomass into sugars, caused by the low efficiency of enzymes and large losses of enzymes during the process.



The growing demand of energy will require harnessing hydrocarbons from waste and other uneatable biomass. Biofuels from such sources will certainly play an important role in our future energy mix.

Here, nano research can contribute new methods for bioengineering of more efficient enzyme complexes, screening of enzymes, and protein immobilization.

Fossil fuels

Nanoscience can help to mitigate the negative effects of fossil fuels by means of new approaches for exhaust purification and for catalysis for removal of unwanted chemicals. The efficiency of power plants could be improved by usage of new nanoparticles with high heat capacity for heat transfer (also for nuclear power plants).

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR SHORT- AND LONG-TERM ENERGY STORAGE:

Since storage of electric energy typically occurs at interfaces, be it the charging of capacitors or electrochemical reactions, a reduction of the typical structure sizes results in an improved surface-to-volume ratio. Nanostructures are thus an ultimate goal for optimal storage density.

Energy density of **supercapacitors** (e.g., Li-ion-capacitors) could be further enhanced by nanostructuring of surfaces (electrodes), and by the usage of new materials, such as graphene, for electrodes. The application of **hydrogen** as an energy storage material could be improved by converting hydrogen into storage materials with higher energy density per volume. For **conventional batteries**, materials for higher density energy storage are desirable, too. Ionic liquids, nanoparticles increasing water heat capacity and phase transition, could be used to store and exchange heat energy.

(Bio)fuel cell catalysis and electrode materials for (bio)fuel cells should be further explored. In addition, nanomaterials could help to reduce friction of mechanical systems, e.g., in rotors.

Environment

The global challenge of the preservation or restoration of a healthy and livable environment touches many of the other identified topics such as energy, food or water. Generally, the potential of nanotechnology was considered in those categories. Explicit problems discussed in this group were:

- CO_2 reduction
- Pollution (toxic materials, smog control, particulate matter)
- Waste and recycling

Here, waste based on polymeric, non-biodegradable materials in the environment was addressed as a specific challenge. Plastic waste is a serious problem, since it represents up to 20% of mankind's overall waste (urban and industrial). Most highly produced plastics are PVC, PE and PP, and half of this waste cannot be recycled. Research on this topic should focus on prevention, degradation and mitigation.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR REDUCTION OF PLASTIC WASTE:

Especially biotechnology and synthetic biology could contribute to the development of a smart cycle of plastic-degrading organisms/enzymes and energy-producing organisms, which convert by-products into useful educts such as new polymers, energy or fuel.

The effects of plastic waste already present in the environment could be mitigated by rational degradation of plastics by microorganisms. The following measures might lead to new degradation pathways:

- Identification of polymer-degrading organisms/enzymes (cheap, robust and efficient)

- (Bio)engineering of new/advanced polymer-degrading functionalities (organisms)

- Implementation of smart metabolic steps for product control (clean byproducts, breakdown to monomers or short oligomers of the polymer, further degradation of by-products into CO_2, H_2O and other small molecules)

- Confinement of biological function to plastic-dense areas

- Regulatory/biosafety switches to remove degrading organisms from local environment after successful plastic degradation.

Material criteria for prevention of accumulation of plastic waste were defined: New materials should be efficiently degraded into bio-degradable, biocompatible byproducts. They should be producible at low costs. Conditional stability, dependent on content, context, structure or locality, could secure degradation of plastic under defined conditions, e.g., in salt water only (to remove waste from the oceans) or after a certain time, e.g., biodegradable and biocompatible thermoplastic (PHA).

Low production costs and superior material properties have made polymeric materials the fastest growing commodity of the petrochemical industry. Today, plastic waste represents up to 20% of mankind's overall waste, and half of this waste cannot be recycled.

Small (less then an inch) hard plastic fragments floating in rivers. The fragments are carried by run-off water to waterways, rivers, and in the end, the sea. Such fragments are mistaken for food by animals and ingested, causing harm and often death.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR OTHER ENVIRONMENTAL CHALLENGES:

The participants discussed the potential of synthetic biology to capture CO_2 by genetically modified microbes and to couple this process with the synthesis of useful products (fuels, commodity chemicals etc.).

Magnetic nanoparticles could be applied for the removal of toxic materials from the environment, while nanoporous materials could be used for exhaust purification and thus smog control.

A new generation of tires should be produced from a material which is stable as bulk (in use on roads) but would safely degrade in the form of nanoparticles. Thus, release of toxic particulate matter by abrasion would be prevented through the follow-up decomposition of released nanoparticles into clean end-products.

Food

As the population on our planet continues to grow, the production and distribution of food will be an ever growing challenge, particularly in times of climate change like we are experiencing today. Nanosciences will play an increasingly important role in dealing with this problem. Food-related challenges can be caused by either production or consumption. Food itself can be divided into two main categories, animal-based food and crop-based food.

Problems generated by animal-based food comprise wastage, pollution and methane production, emergence of antibiotic resistance, and health and environmental issues, e.g., due to use of growth hormones or pathogen transmission. In addition, standards of production, costs, availability and distribution of animal-based food have societal and ethical implications.

Crop-based food on the other hand, can affect the environment depending on production methods by wastage, pollution and distribution, e.g., local/regional versus global production. Other factors to be considered, especially in view of the increasing world population, are food availability, production costs, and health issues.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR FOOD PROBLEMS:

SMART(e)R soil

SMART(e)R soil, a low-cost, nutrient-enhanced soil supplement that enables plant growth in environments that would not otherwise support healthy plant growth, would be ideal to improve environmentally friendly crop production. Ideally, it should consist of a mechanically stable composite material consisting of millimeter-sized support granules and nutrient-adsorbing particles. This prevents nutrients from being washed from productive topsoil and transported to unproductive lower soil. SMART(e)R soil could improve crop quality, crop yield and land productivity. SMART(e)R soil could also enable more efficient fertilizer usage, thereby reducing growth costs and damage to the environment. Because it is a granular material, SMART(e)R soil could be packed in a space-efficient manner and shipped to a wide variety of locations in large volumes at a low cost per unit. Reduced environmental pollution, improved crop quality and improved crop yield should lead to improvements in population health. Malnutrition associated with inadequate food resources could also be reduced.

Basic Food Resource (BFR)

The growing resource demand due to growing populations could be secured by a Basic Food Resource (BFR) – a simple, low-cost, easy-to-grow food source that meets the basic nutritional requirements of the average human being. The BFR would be a simple alga capable of being grown in low-cost, fertilizer-free, water-containing reactors. These reactors should be deployable in a wide range of environments (e.g., rural, urban rooftop, etc.).

They should provide basic properties enabling and supporting effective algal growth, including:

- Selective gas permeability
- Light permeability
- Heat capture
- Non-adhesive walls (to prevent reactor fouling)
- Adjoining cyanobacteria-based support reactor for N_2-fixation.

Here, nano- and biotechnology could contribute to finding solutions for the following requirements:

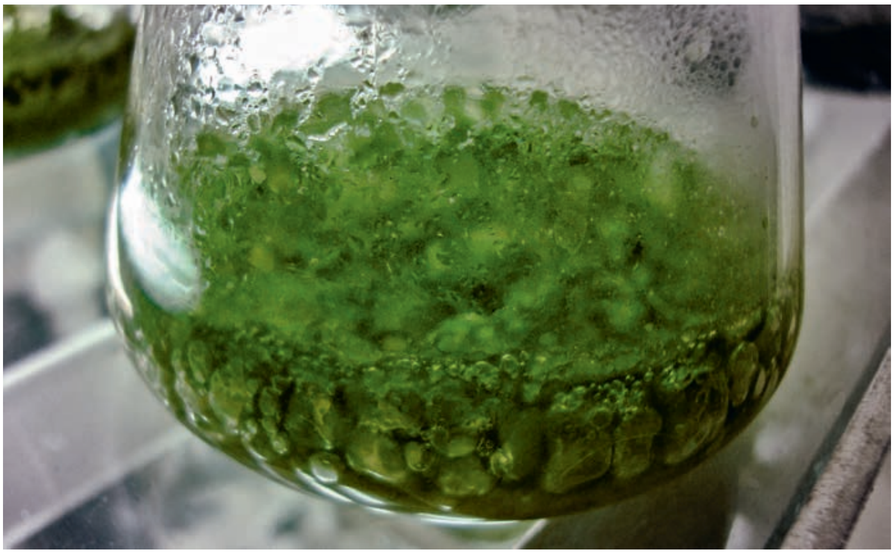
- Genetic engineering of the alga to provide all essential nutritional needs

- Surface and material engineering of the reactor vessel walls

- Scalability to enable housing on the average urban rooftop.

Artificial meat

The demand for animal-based food could be satisfied by artificial meat – a healthy, low-cost, easy-to-produce artificial alternative to animal meat. This could be used, for example, as a substitute for meat in regions where animals cannot be raised, transported or sustained. This could also be used as a low-cost substitute for meat found in products where the texture of the meat is less critical than in other foods, e.g., in frozen pizza. Nanotechnology could help to meet requirements such as controlled structure/texture, controlled taste and controlled nutrition and nutritional delivery. Artificial meat as described above could be produced faster, on a larger scale and in a wider variety of environments than natural animal meat, e.g., in regions that do not naturally support the production of natural animal meat. This could lead to improved access to food, reallocation of land to support crop growth, and also greater local and regional employment. Since the production of animal meat requires large quantities of feedstock, drinking water and agricultural land, artificial meat produced on an industrial scale would likely be more resource efficient. Artificial meat could be produced in a wide variety of environments and could be shipped in larger quantities more efficiently. A greater dependence on artificial meat could lead to a significant reduction in the large quantity of environmentally harmful methane gas ejected into the atmosphere by cattle, and would also lead to reduced antibiotic resistance in the human population caused by the presence of antibiotics in cattle and other animals. The spreading of animal-borne diseases amongst the human population could also be greatly reduced, especially in countries where animal handling methods are less well developed. Last but not least, a reduced dependence on animal meat leads to the killing of fewer animals.



Algae as a basis for a Basic Food Resource (BFR) can be grown in fertilizer-free, water-containing reactors in a wide range of environments.

Health

Affordable health care for a growing and, at the same time, ageing population, especially in the western world, is one of the largest challenges. The growing disparity between scientific progress and applied medicine demands urgent solutions, and nanosciences offer potential solutions.

A) PREVENTION

Vaccines are ideal means to prevent infectious diseases caused by bacteria or viruses. There are several bottlenecks in the use of vaccines, both in production and in distribution. The first one is manufacturing process optimization towards facilitating regulation of bio-products (cheaper, safer, more efficient use). Many new vaccines that are developed can never be used due to difficulties in mass-manufacturing them. Special challenges are faced when producing vaccines: they are administered to (a) healthy individuals, (b) children and (c) individuals of all ethnicities, BUT it is almost impossible to create a biopharmaceutical which is 100% safe, has no side effects and is always efficient. This is due to the inherent variation present in biological materials and because it is not known how process conditions affect the product. Moreover, regulatory agencies cannot approve vaccines which are effective for only a subset of the world's population – this needs to be counteracted because approving a vaccine which works for 30% of the world's population (for example against malaria) would still save millions of lives. This would ease the burden on manufacturers and regulators alike, it would make vaccines cheaper, safer and more varied.

A second bottleneck is the stable formulation and adjuvants of the vaccine. Making existing vaccines available in regions with unfavorable climates requires these measures. One of the largest costs to health care and a challenge in rural areas and developing countries is the refrigeration of vaccines.

With the rise of genetic sequencing capabilities and development of rapid, low-cost biosensing techniques, the potential for **personalized medicine** is becoming a reality. This powerful tool can be used not only in diagnosis and disease progression monitoring but in screening and disease prevention. The identification of risk factors is already leading to lifestyle changes but rather than simply recommending only behavioral changes to persons in an identified risk group for a non-infectious disease, therapeutics should ideally be developed to block the mechanisms which trigger the onset of disease progression.

Taking steps at a presymptomatic stage and altering the body's behavior could prevent what would otherwise develop into chronic diseases which need lengthy and occasionally invasive treatment and which are extremely costly, resource-intensive and detrimental to patient quality of life. For example, in the case of heart disease, if those who are predisposed to the disease can be identified at an early age and treated with a therapeutic, for example, a nanoparticle, to reduce the adhesion of fat to the lining of arteries, this would avoid the later need to treat symptoms, using, e.g., drugs to reduce blood pressure or extensive open heart surgery for grafting.

The ambiguities of **nanoparticle safety** are an obstacle not only to regulatory approval but also to the effective incorporation of nanoparticles into drug development, formulation and targeted delivery mechanisms. The continued compilation of current knowledge of the biological effects of nanoparticles, over a range of sizes and materials, would enable much more efficient research practices and also increase acceptance and trust in nanopharmaceuticals.

Community health worker gives a vaccination in Odisha state, India. Vaccines are ideal means to prevent infectious diseases caused by bacteria or viruses.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR PREVENTION OF DISEASES:

Vaccines

Process analytical technology (PAT) can be used to monitor bulk production, for example biosensing devices for biophysical characterization of the bioproduct. Such biosensing devices should work in real time, in-process and have a high throughput so that quality aspects of the bulk product can be monitored. Separation processes based on chromatography techniques could be used in conjunction with the specific biorecogition techniques used in biosensing technology to provide the specificity to achieve the purity required for pharmaceuticals.

For approval of vaccines effective for only a subset of the world's population, better tools for biophysical characterization of vaccines during manufacturing and for efficient identification of relevant population subgroups are needed. In addition, new formulation of vaccines which allows for storage under atmospheric conditions could facilitate distribution in developing countries.

Personalized medicine

The main steps identified as critical for the emergence of preventative medicine are:

- Genetic sequencing and correlation with biomarkers for risk for disease
- Identifying biomarkers for pre-symptomatic disease progression
- Development of biosensing devices to monitor pre-symptomatic disease progression
- Developing drugs to target these biomarkers and block disease progression. This can happen in conjunction with corresponding alterations to lifestyle/behavior.

Nanoparticle safety

Research on this topic should include information such as the effect of route of administration and the mechanism of degradation. Bioclearance, immune response, accumulation in different organs, toxicity etc. for the various size ranges, distributions and initial dose to determine safe exposure limits should be investigated.

B) DIAGNOSTICS

Many diseases can be cured or at least contained when diagnosed sufficiently early. However, current diagnostics rely on the use of costly and time-consuming methods and tools. A **Point-of-care diagnosis biosensor** could alleviate this problem, provided that it is:

- Widely available and affordable
- Highly sensitive and specific
- Ideally quantitative (semi-quantitative)
- Reliable, compact and robust
- Easy to use.

A suitable sensor will also enable the deployment of affordable diagnostic tools to developing countries, reduce the time between diagnosis and treatment of a disease, and would be of great use in detecting asymptomatic diseases during routine check-ups.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR DIAGNOSTICS:

Biosensors are composed of a biointerface (that recognizes and binds the analyte of interest) and a transducer (that converts signals generated by the interaction into a readable form).

Common biointerfaces and transducers are shown in → Table 2. Please note that only stable bio-interfaces are presented.

A short-/medium-term solution (→ page 22) is presented and combines existing solutions into a single tool to create a more efficient, more reliable bio-sensor. A long-term vision, relying on a bio-mimetic approach (→ page 24) is also presented for the development of a new generation of highly sensitive bio-sensors.

BIOINTERFACES	TRANSDUCERS
Antibodies	Surface plasmon resonance
Peptide Nucleic Acids (PNA)	BioFET
Imprinting methods	Resonance [Surface Acoustic Wave (SAW), Film Bulk Acoustic Resonator (FBAR), Longitudinal Bulk Acoustic Resonator (LBAR), etc.]
Proteins	Deflection (Membrane, cantilever, etc.)
Functionalized nanoparticles (NPs)	Impedance
Nanoparticles	Optical (FRET, absorption of light, etc.)

Table 2: Examples of biointerfaces and transducers for point-of-care biosensors.

C) TREATMENT

Identification of drugs and drug targets

Both synthetic drugs and naturally derived drugs should be considered. Nanotechnology can provide improved screening technologies for drug (bioprospecting) and drug target identification and computational science for rational drug design. A better understanding of cellular processes on the nanoscale will help to address new target structures in diseased cells.

Improve drug design

Drugs should have high bioavailability and specificity and show low immune response and toxic side effects. Smart nanoparticles that consist of polymers, liposomes, inorganic material (silica), or metals are currently investigated. Targeting ligands can be attached to achieve specific treatment of diseased cells. Bioresponsible linkers that sense pH, temperature, surface molecule or light might allow localized drug release at defined time-points at a chosen dose. Applied materials should be biodegradable and one should focus on FDA-approved materials and naturally derived products that are known to show low side effects. Novel chemistries and/or nanoscale constructs may open up previously inaccessible biological sites for exploitation (e.g., crossing the blood/brain barrier).

Point-of-care Diagnostics: Malaria Rapid Diagnostic Test (RDT). Specific challenges for the development of Point-of-care diagnostics are high sensitivity and specificity, reliability, robustness, easy usability and costs.

Encapsulating already existing drugs could improve biodistribution, delivery and diminish toxicity. Gene therapy by viruses or artificial gene vectors can provide treatment of severe diseases (genetic diseases, cancer, cardiovascular diseases in the future). Nanoparticles in combination with dialysis can also be used to filter toxic substances or pathogens from the blood circulation. Genetically modified mosquitos were discussed for malaria treatment. Last but not least, DNA origami or DNA nanostructures were considered as a promising tool for the design of smart nanoparticles.

Production

An important and urgent task that should be addressed is the scalability of drug production. Drug production and purification has to be cheap and fast (time-scale). Nanotechnology can improve the quality control processes in production (more sensitive tests, lab-on-a-chip) and the purification process. New materials might reduce the cost of treatment. The stability of drugs needs to be addressed to improve transport and storage. DNA chemistries (XNAs) can be used to enhance stability.

Clinical Application

Education is important to reduce inappropriate application of drugs/medication that leads, e.g., to antimicrobial resistance. Personalized medicine should be applied (e.g., specific targeting for specific cancer subtypes). The genomic or epigenomic background of each patient should be considered. In addition, the response of the patient to the medication should be monitored (nanotechnology can provide point-of-care diagnostics).

Tissue Design

New implants can be designed by nanotechnology. Stem cell technology can help to build organs.

POTENTIAL OF NANOTECHNOLOGY RESEARCH FOR DISEASE TREATMENT:

Nanotechnology-based solutions to the problem of resistance to antibiotics

Current antibiotics have a relatively long half-life, resulting in significant amounts of antibiotics remaining in the colon at sub-lethal concentrations and facilitating the evolution of resistance. Analogously, after leaving the body, low concentrations of antibiotics in the environment provide reservoirs for the evolution of resistance. As a consequence of the dramatic rise of antibiotic resistance many potent antibiotics become ineffective, raising the need for immediate alternative solutions. Nanotechnology offers valuable tools to develop novel antibacterials, to improve the efficacy of existing antibiotics and to develop rapid, cost-effective point-of-care diagnostics.

Improving the efficacy of existing antibiotics could contribute significantly to successful treatment of bacterial infections. Using nanocarriers for drug delivery offers a simple way to enhance the efficacy of existing antibiotics, via targeted and responsive (only active at the site of infection) delivery. In addition, drug delivery inside host cells (e.g., Mycobacterium tuberculosis lives inside macrophages) could be improved by nanocarriers. Such nanocarriers should be cost-effective and biocompatible: Chitosan, DNA/XNA nanostructures (origami based), BSA and PVA are possible carriers.

Novel antibacterials: Natural nanobiotics should be further explored, e.g., antimicrobial peptides. Problems like toxicity could be overcome by using carriers for delivery.

The efficacy and toxicology as well as environmental implications of artificial nanobiotics (e.g., metal nanoparticles, carbon nanotubes) should be investigated. Possibilities for breakdown (or at least removal from the body) of metal nanoparticles or carbon nanotubes should be addressed.

Phage Therapy (viruses that attack bacteria) has potential drawbacks that nanotechnology could mitigate. Better purification could be achieved by new types of membranes and advanced filters. Genetic engineering could help to (i) alter the evolvability of phage (and the potential dangers associated with evolved phage such as broadening of the host range) by incorporating high fidelity polymerases and (ii) suppress unwanted immune responses. Design of non-replicating phages which can be administered by the body but are not able to ramain there latently for a long time is desirable. Last but not least, the use of phages as biofilm-degrading agents would be an interesting application.

Combinatorial drug delivery (of different existing antibiotics and novel natural antibacterials) via efficient nanocarriers leading to synergistic antimicrobial effects would offer new options for treatment of bacterial diseases.

Point-of-care testing (POC): Time-consuming culture based techniques are still widely used to determine the species that causes a bacterial infection. However, there is a need to develop rapid and less labor intensive techniques. Therefore, point-of-care testing (POC) for bacterial infections should be developed. Currently, PCR is used to detect specific DNA sequences that can distinguish between resistant and non-resistant strains and to adjust therapy accordingly. However, this method is expensive and requires skilled workers, electricity and lab facilities. It would be helpful to develop non PCR-based methods to detect DNA and RNA in a POC platform. The use of plasmonic properties of (gold) nanoparticles provides opportunities to develop methods to detect nucleic acids without PCR. Short DNA or RNA probes can be used to make colloids aggregate, causing a change in color upon plasmonic excitation.

Optimizing antimicrobial materials used in various settings (e.g., hospitals, food industry) to prevent bacterial growth and biofilm development by using nanocoatings could significantly improve existing hygiene measures.

Improvement testing of antibiotics: Natural bacterial habitats are heterogeneous in space and time. Traditionally, microbiologists use well-mixed environments to study the efficacy of antibiotics, whereas in the human body concentration gradients across space exist and concentrations fluctuate through time. Nanofabrication and microfluidics provide the tools to create artificial 'ecosystems' to mimic the natural heterogeneity of antibiotics and study its influence on the evolution of resistance and the development of non-inheritable resistance (tolerance) to antibiotics.

New materials

New materials were defined as a challenge which has strong implications on other challenges such as health, environment, food, energy etc. The participants decided to focus on highly adaptive and controllable materials. Three key areas of adaptive materials were identified: self-healing, self-cleaning and shape memory materials.

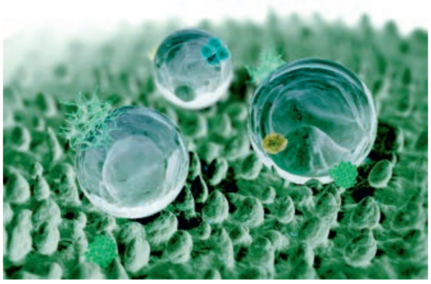
Self-healing materials would be ideal construction materials. Damage to exterior and support structures in buildings requires costly repairs or results in abandonment of the structure. This is particularly acute in catastrophic natural disasters, such as earthquakes, where damage to large population centers results in loss of life and billions of dollars in damage. Countries which do not have the infrastructure immediately available after a catastrophe suffer particularly, and so quick repairs will aid better response in these situations. The materials may also be able to repair micro-failures in the structure on a daily basis to stave off larger structural failure over time, creating a more sustainable building material.

Incorporation of self-healing materials would allow for quick and effective repair of these structures, reducing the loss of life and the time and cost of repairs.

Self-cleaning materials could represent a major advantage in medicals tools for developing countries, where surgery takes place in poor hygienic conditions. These materials would represent a new platform for bacterial prevention, limiting the causes of infections. Ideally the self-cleaning materials would be a preventative measure, reducing the presence of bacteria in surgery environments, food handling, and medical tools (i.e. bandages, sutures, scalpels, surfaces).

Shape memory materials are materials that will return to their pre-deformed state when external stimuli (most often heat) are applied. This kind of material is already applied in various real-world devices like medicine (e.g., stents, orthopedic surgery), optometry or different industrial applications. However, there is still a lot of work to be done in order to find other fields of application to tackle some important global challenges.

External stimuli such as light, heat and electricity can be used to effectively and cheaply have materials adapt their properties to current needs. The incorporation of polymers able to react to such stimuli can be combined with materials providing structural integrity to the material, leading to superior properties.



Nanostructured hydrophobic surfaces were invented by mother nature to keep leaves clean. Learning her tricks may help do design tailored materials for a variety of applications.

Water

In recent years, water as the basis of life has become a scarce resource and its quality a matter of serious concern. Here again nanosciences may offer solutions particularly in desalination and detoxification. The group started by looking at the various issues involved in water, including water for agriculture, water for drinking, and wastewater treatment. Later, the participants focused on drinking water as the most pertinent issue. Their approach was to imagine a dream device for water purification and the properties it requires.

A dream device (→ Figure 3) would be able to remove multiple types of contamination from water, including heavy metals, microorganisms, and organic and inorganic contamination. It would also indicate the level of cleanliness with a user-friendly sensor, for instance a color sensor. In a dream world, there would be some kind of indicator that would sense all types of contamination simultaneously, perhaps a "canary organism" that would only live in potable water. In addition, the device should be inexpensive, easy to use, energy efficient or even self-sustaining, and modular and adaptable to different conditions and contamination types.

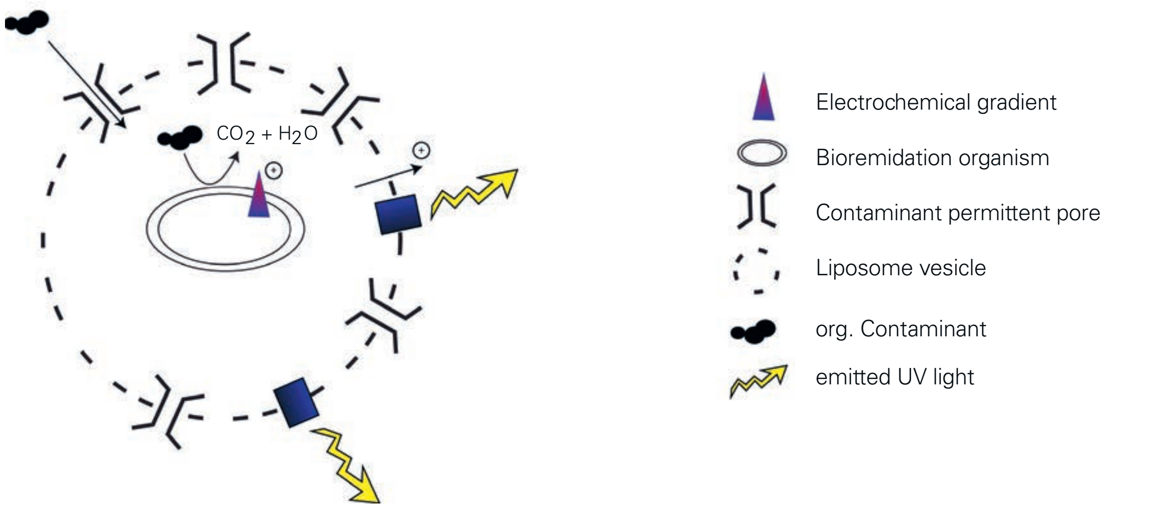


Figure 3: Summary of an imagined "dream nano water purifier" that the group developed. Organic contaminants (black blobs) enter a liposome vesicle (dashed line) through pores. There, they are broken down by an organism (oval), which also creates an electrochemical gradient (triangle). This electrochemical gradient is then converted into ultraviolet light (yellow lightning bolts) by a protein in the liposome (blue squares). The UV light helps to further decontaminate the water. The group noted that, while there would clearly be a number of technical issues with building this device today, a "dream device" such as this can point the way toward technologies that are worth developing.

Finally, it should be re-usable and even potentially able to recover materials for re-use – for instance metals.

POTENTIAL OF NANO-TECHNOLOGY RESEARCH FOR PROBLEMS RELATED TO DRINKING WATER:

There are many ways to create a device such as that described above. Currently, people filter water using materials such as clay, cloth, or carbon filters, which remove microorganisms. The participants envisioned using bacteria to aggregate smaller pollutants such as heavy metals or phosphates, then collecting the bacteria in a filter. They also discussed using nano-encapsulation, for instance with liposomes, block copolymer traps, or polymer vesicles to achieve the same effect. These nano-encapsulation techniques might use engineered ion channels or other proteins to allow contaminants into the chamber. For example, much could be learned by studying extremophiles, especially those that already live in contaminated water. Energy could come from light-driven pumps, biological energy sources, or taking advantage of molecular motors. Current work using aquaporins and functionalized magnetic nanoparticles to filter water could be integrated into such an approach.

Energy for filtration devices derives from a number of sources. Light-driven pumps could make their own energy, as could certain types of microorganism. Mechanical sources such as gravity, suction, or capillary forces could be used. Gradients are a useful method of driving filtration.

Distribution of potable water. Nanosciences may offer solutions particularly in water desalination and detoxification.

In addition to filtration, distillation and sterilization are important techniques for the purification of water. The group briefly discussed the application of nanostructured materials to improve solar stills, for instance materials that absorb a great deal of light.

A filter that uses gravity to filter water is already in use (LifeStraw). This device is cheap and reusable. Aquaporins are also being brought to market for filtration. The open questions in aquaporins appear to be at the single molecule level. For instance, it is not well understood how contaminants in the water affect aquaporin filtering function. Biofouling is a major issue facing established filtration technologies.

Another category involved the use of liposomes. It is currently possible to fabricate liposomes in which porins are incorporated, which can be gated by sugars. A wide range of control over the permeability of the membrane is possible, allowing for selective sequestration of a variety of chemical species. It was also noted that there would be wide application for a nanoscale UV emitter, potentially allowing for greater efficiency in UV sterilization. Bioremediation (decontamination by microorganisms) could be implemented in these vesicles, for instance mycoremediation, which is remediation by fungi, can adsorb pollutants and transform pollutants into CO_2 and H_2O, and a redox potential, which could in turn be used as an energy source.

There are many tests for different types of contamination, but no “canary organism.” In some parts of the world, certain types of flies are only observed when the water is pure, which people use as an indicator of water quality.

Basic science could help advance water filtration by improving understanding of the molecular structure of water at interfaces. These structures are especially poorly understood when other chemical species are present in the water.

Opportunities for Nanoscience and for

In the last part of the workshop, participants started to apply the existing expertise of the group and to develop new ideas in an interactive manner, spanning different disciplines and nationalities. As a result, interesting possible projects in some of the identified areas were established. Due to their preliminary state, only a limited selection was incorporated into this report and the description of the projects must remain superficial.

DISPOSABLE MULTIPLEX BIO-SENSING ARRAY FOR POC DIAGNOSIS

Challenge

Current sensors are usually composed of one bio-interface and one transducer. Here we propose a novel approach that will take bio-sensing to another level. The combination of two or more transducing elements used simultaneously to probe a nano-structured bio-interface will improve the reliability and specificity of the sensor and enable the detection of a wide variety of diseases.

Key advantages

A dual transducer sensor will probe the bio-interface with two independent methods, increasing reliability. It will also enable the detection of contaminants or non-specific interaction (see → scenario 1 below) and enable diagnosis of "conformational diseases" such as Alzheimer's, Parkinson's, and Creutzfeld-Jakob, etc. (see → scenario 2 below). The bio-interface of the sensors will be nanostructured to increase specificity and improve sensitivity (in the case of an acoustic transducer). The biointerface will also be selected so as to minimize the impact of the epigenetical differences among patients.

Scenario 1: A gravimetric sensor cannot differentiate a non-specifically bound large molecule from specifically bound target analytes of total equivalent mass. However, assuming both have different sizes and shapes, it will be possible to differentiate between them using a complementary technique such as Surface Plasmon Resonance (SPR) that measures the surface coverage or resonators that measure hydrodynamic properties of the analytes.

Scenario 2: Conformational diseases (Alzheimer's, Parkinson's, and Creutzfeld-Jakob, etc.) are difficult to diagnose: In addition to being able to detect a specific protein, one should also be able to determine if it is misfolded or not. It is obvious that in those cases a gravimetric or surface coverage transducer alone could not differentiate misfolded from wildtype proteins. Resonators whose responses depend on the interaction between the analyte and the surrounding fluids (hydrodynamics) are better suited; however, the models are quite complicated and it is currently impossible to differentiate a homogenous layer of misfolded protein from a heterogenous layer of wild-type proteins. Models could be used quite reliably, however, provided that one parameter, such as the mass, is fixed. This could be achieved using a complementary gravimetric sensor.

Solution

Our plan is to design a smart, integrated device with exchangeable and disposable cartridges. The cartridges will be disease-specific or region-specific, i.e. they will be sensitive to biomarkers specific to a chosen disease or to multiple diseases prolific in the target region (e.g., HIV, malaria, and TB in Africa). Each cartridge will consist of an array of sensors, including a reference sensor to compensate for any signal drift (due to temperature, evaporation etc) and to take into consideration the non-specific interaction. Each sensor will use the same transducer platform, while the bio-interface will be chosen and functionalized to bind the appropriate molecules. This will result in a single, simple-to-use device for the detection of various diseases. The cartridges, made of silicon, will be mass-produced using conventional micro-fabrication techniques and will feature electronics for the readout and/or actuation through CMOS integration. It will therefore result in a low-cost disposable device. The planar sensors could easily be interfaced with a microfluidics circuit to integrate further functions. Two potential sensor designs are presented below:

Design 1: The transducer platform will combine surface acoustic wave (SAW) and surface plasmon resonance (SPR) measurements in a single device. The SAW technique will provide information about the evolution of the mass and viscoelastic properties of the film formed on the surface, which can then be related to the binding of analytes, while SPR will probe surface coverage. Impedance measurement could also be easily implemented in parallel.

A nano-imprinting technique will be used to create a bio-interface suitable for detecting small molecules. Shape- and size-specific binding sites will be created by electro-polymerization of functionalized gold nanoparticles in the presence of molecules similar to the target analyte. To detect proteins or nucleic acids, a nanostructured interface incorporating antibodies, aptamers or peptide nucleic acids (PNA) will be used. The structure will be designed to increase the available bio-interface area and thus minimize the time of detection needed to bind a bio-analyte.

Design 2: The transducer will consist of a silicon membrane that can be used in deflection or resonant mode. The deflection mode can be measured piezo-resistively and does not require actuation. This will enable the measurement of mass changes on the membrane. The resonant mode requires electrostatic actuation (DC bias and AC) and a capacitive or piezo-resistive output can be measured. This mode will provide information about the mass and viscoelastic properties of the binding analytes. The solid on liquid deposition (SOLID) technique will be used to prevent fluid flowing between the electrode and the membrane. Impedance measurement could also be easily implemented in parallel for the analysis of the desired analyte.

A nanostructured bio-interface will be functionalized with antibodies, peptide nucleic acids (PNA) or aptamers to target specific bio-markers. This sensor platform could be used for detection of bio-markers in air or liquid.

Summary

A single simple-to-use platform with affordable disposable cartridges to detect various diseases is proposed. Silicon-based sensitive MEMS transducers allow for conventional microfabrication and CMOS integration, miniaturization and mass production and thus for a low cost, compact device. Two or more transducers are combined to probe the same bio-interface, resulting in a higher level of confidence (two independent measurements). The device allows for high specificity by detecting contaminants/non-specific interactions. In addition, it is possible to differentiate the type of interaction and surface coverage, potentially enabling a semi-quantitative detection of molecule shape (useful for the detection of protein misfolding that occurs in "conformational diseases" such as Alzheimer's, Parkinson's, Creutzfeld-Jakob etc.). The nanostructured bio-interface allows for a high specificity and potentially increased sensitivity (for acoustic transducer).

HIGHLY SENSITIVE BIO-SENSOR BASED ON TRANS-MEMBRANE PROTEINS

Challenge

Some bio-markers (analytes) are found in very low concentrations in biological fluids. Current sensors usually use amplification (for nucleic acid-based sensors) or concentration methods to detect such bio-markers. However, those methods can be time-consuming and are often complicated and expensive. Drawing inspiration from life science, a novel biomimetic sensing platform is proposed where a molecule (e.g., a protein) can trigger an avalanche of events on the other side of a synthetic membrane when coupled to the appropriate trans-membrane protein (→ Figure 4). The sensor would detect the events triggered by the interaction of the target analyte with an engineered trans-membrane protein.

Solution

The platform could be a microfluidic device comprising a channel with side chambers. The biological fluid of interest would flow in the main channel and a synthetic membrane with engineered trans-membrane protein receptors would separate the main channel from the small compartments. When the analyte (ligand) of interest couples to the trans-membrane protein, it triggers an avalanche that can be detected by the sensors in the chambers. The example of a ligand-gated ion channel is shown below.

Another approach could be to use vesicles with trans-membrane proteins. They would be mixed with the biological fluid of interest in a single channel and the coupling of the protein of interest would trigger an avalanche of events inside the vesicle, which could be detected by impedance measurement, for example.

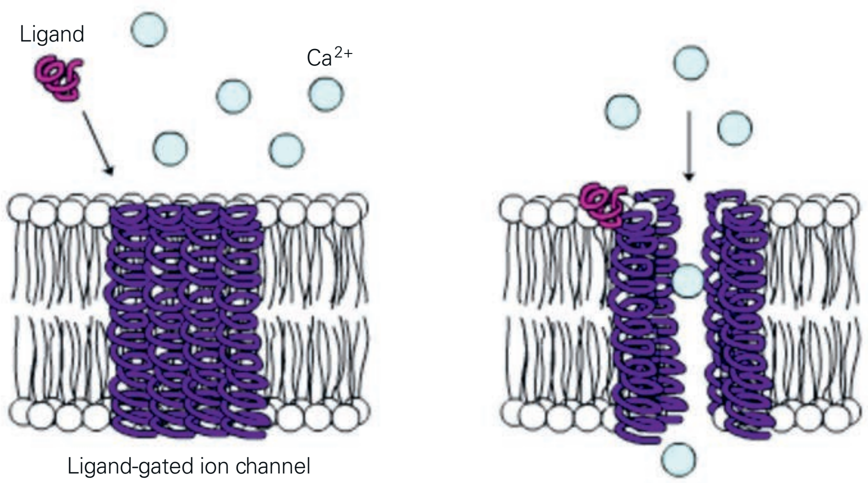


Figure 4: Sketch of a ligand-gated ion channel (LGIC), which is a trans-membrane protein that opens and lets ions flow through upon binding of the ligand. Source: Wikipedia

LAB@HAND

Challenge

The money spent treating the symptoms of civilizational diseases could be significantly reduced, if early-stage diagnosis was implemented. One of the possible solutions is wide, probably obligatory screening; however, it is costly and time-consuming, as the screening needs to be repeated at regular intervals. Thus, other solutions are needed.

Susceptibility to some of the world's most common diseases has some genetic background. Thus, if a person knows that the risk for specific disease is increased among their relatives, the person needs to be monitored regularly for early symptoms of the disease.

Solution

We propose a personal diagnostic device. The heart of it is an intelligent wristwatch. The watch reads and processes the signals from various sensors located either directly in the wristwatch (sweat, breath, through-skin optical methods) or an intelligent microdevice located below the skin and by-passed to the blood vessel.

Underskin intelligent microsensor

There are great advances in miniaturization and the development of novel biointerfaces (specific antibodies, proteins, functionalized nanoparticles) and transducers (mechanical – cantilever-based, acoustic, e.g., surface acoustic waves, plasmonic, etc.). This opens new possibilities to construct a microdevice which can measure several different biosignals: both standard (blood pressure, glucose concentration, NO, O_2) and specific (binding to biomarkers). There is no need for a battery: due to low power consumption, the capacitor integrated with sensors can be charged remotely (through electro-magnetic induction). Thus, the microdevice, once inserted subcutaneously by a surgeon, may stay there for the rest of a person's life.

TISSUE ENGINEERING AND DNA ORIGAMI

Challenge

In an ageing society, bone diseases like bone fractures, bone cancer, bone metastasis and osteoporosis have a major impact on quality of life. Current bone regeneration research for the reconstruction of critical sized bone defects is focused on immobilization of bone morphogenic protein 2 (BMP2) within a hydrogel matrix. BMP2 is an essential component for bone growth.

The diffusion of BMP2 to the cells in need of it is very inefficient, requiring large doses of BMP2. Such large doses have been shown to lead to several complications such as ectopic bone growth and cancer resurgence.

Solution

Functionalizing polymeric scaffolds with DNA origami-based encapsulation of BMP2 will result in more precise delivery of the growth factor, while minimizing the detrimental effects.

To incorporate the DNA origami into large volume tissue engineering scaffolds, the production of the DNA origami needs to be scaled up. Implementation of a microfluidics approach to create an array of bioreactors can effectively assemble substantial quantities of DNA origami bases required for such an application.

The above is only one example of the benefits of such technology and can be tested in the short term. In the long term, such growth factors can be implemented for the regeneration of virtually any organ of the body. Revascularization of tissue engineering constructs can also be achieved by targeted delivery of growth factors such as VEGF, EPHB etc. near the scaffold implantation site.

Conclusions

FEEDBACK: HOW MAY THE WORKSHOP BE IMPROVED?

Most of the participants found the group discussions in this workshop to be intensive and fruitful, especially due to the diverse and interdisciplinary backgrounds of the group. The input of the invited experts was unanimously praised.

For a follow-up workshop, it was suggested to give more time for the development of new nanotechnological approaches. Web-based communication was proposed to facilitate preparation of the workshop beforehand, e.g., by creating research profiles of all participants, allowing for networking and the formation of teams with complementary expertise. Also, the identification of challenges could be prepared before the workshop, thus saving time for in-depth examination of new research approaches. Web-based communication could also be used for exchange of ideas and information after the workshop and to facilitate new collaborations. The organizers and participants agreed that rapidly obtaining answers to the questions raised by the discussion groups, especially by faster internet access, would tremendously improve the quality of the analysis.

CONCLUDING REMARKS

The intention of this meeting was to bring together young nanoscientists with diverse scientific and cultural backgrounds to form an interdisciplinary network and to develop new (technology and engineering) strategies towards targeting global challenges. Of course, the list of challenges and their solutions discussed during the meeting is not exhaustive, but rather a snapshot of the current view through the eyes of our next generation of scientists, since the time allocated was much too short for a profound analysis. The discussions in this multicultural group acted as an eye opener for everyone and increased the young scientists' awareness of global problems and their potential contribution to the solution of these problems. The organizers are confident that some of the projects developed during the workshop will be the seeds for new research ideas and for the formation of a vibrant network amongst talented young minds from all over the world. This report will be made available to the global decision makers with the intent of informing them on the young scientists' view of the situation and their potential solutions.

Participants of the Global Challenges Workshop 2013.

Venice International University, San Servolo.

Appendix

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GLOSSARY

Antimicrobial peptides Peptides of 12–50 amino acids, found among all classes of life with potent, broad spectrum antibiotic effects.

Aptamers Oligonucleic acids or peptide molecules that bind to a specific target molecule.

Aquaporins Proteins that form pores in the membrane of biological cells.

Bioavailability Fraction of an administered dose of unchanged drug that reaches the systemic circulation.

Bioclearance Rate at which a substance is removed from the blood.

Biocompatibility Ability of a material to perform with an appropriate host response in a specific situation.

BioFET (field-effect-transistor) A complex multi-scale system where a semiconductor device is coupled to a bio-sensitive layer that detects bio-molecules in a liquid.

Biomarkers Indicators of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention.

Bioremediation Use of micro-organisms to remove pollutants.

Biosensor Analytical device that combines a biological component with a physicochemical detector to detect an analyte.

Block copolymer Polymer made up of blocks of different polymerized monomers.

BSA (Bovine Serum Albumine) Serum albumin protein derived from cows.

Canary organism Organism which responds to toxic substances at much lower concentrations than humans can detect.

Capacitor (also known as a condenser) Passive two-terminal electrical component used to store energy electrostatically in an electric field.

Carbon nanotubes Cylindrical carbon molecules with unusual properties, diameter close to 1 nm.

Chitosan Linear polysaccharide, made by treating shrimp and other crustacean shells with sodium hydroxide.

Chromatography Collective term for a set of laboratory techniques for the separation of mixtures.

CMOS Complementary metal–oxide–semiconductor, a technology for constructing integrated circuits.

Composite material Materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.

Conformational disease Disease caused by adoption of non-native protein conformations that lead to aggregation.

DNA origami Nanoscale folding of DNA to create arbitrary two and three dimensional shapes at the nanoscale.

Dye-sensitized solar cells (DSSC) Low-cost solar cell belonging to the group of thin film solar cells.

Ectopic bone Bone which develops in abnormal sites.

Electrospinning Method which uses an electrical charge to draw very fine (typically on the micro or nano scale) fibres from a liquid.

Epigenome Chemical modifications to DNA and histone proteins form a complex regulatory network that modulates chromatin structure and genome function. The epigenome refers to the complete description of these potentially heritable changes across the genome.[1]

Exposure limits a legal limit for exposure of an employee at a workplace to a chemical substance or physical agent.

Extremophil Organism that thrives in physically or geochemically extreme conditions that are detrimental to most life on Earth.

FDA U.S. Food and Drug Administration.

FRET Förster Resonance Energy Transfer, a mechanism describing energy transfer between two chromophores (part of a molecule responsible for its color).

Genetic engineering Direct manipulation of an organism's genome using biotechnology.

Gravimetric sensor Sensor based on measurement of the strength of a gravitational field.

Heat capacity Measurable physical quantity that specifies the amount of heat required to change the temperature of an object or body by a given amount.

Hydrogel Network of polymer chains that are hydrophilic, sometimes found as a colloidal gel in which water is the dispersion medium. Hydrogels are highly absorbent (they can contain over 99.9% water) natural or synthetic polymers.

Impedance Measure of the opposition that a circuit presents to the passage of a current when a voltage is applied.

Imprinting (molecular) Technique to create template-shaped cavities in polymer matrices with memory of the template molecules to be used in molecular recognition.

Ion channel Pore-forming membrane proteins present in the membranes of all cells, whose functions include establishing a resting membrane potential, shaping action potentials and other electrical signals by gating the flow of ions across the cell membrane, controlling the flow of ions across secretory and epithelial cells, and regulating cell volume.

Ligand Substance (usually a small molecule) that forms a complex with a biomolecule to serve a biological purpose. In a narrower sense, it is a signal triggering molecule, binding to a site on a target protein.

Lignocellulose Plant dry matter (biomass), composed of carbohydrate polymers (cellulose, hemicellulose), and an aromatic polymer (lignin).

Liposome Artificially-prepared vesicle composed of a lipid bilayer.

MEMS transducers Microelectromechanical systems-based device that converts a signal in one form of energy to another form of energy.

Microfabrication Process of fabrication of miniature structures of micrometre scales and smaller.

Microfluidics Deals with the behavior, precise control and manipulation of fluids that are geometrically constrained to a small, typically sub-millimeter, scale. Typically fluids are moved, mixed, separated or otherwise processed.

Nanobiotics Nanoparticles with antibiotic properties.

Nanocarriers Nanomaterial being used as a transport module for another substance, such as a drug.

Nano-encapsulation Coating of substances within another material at sizes on the nano scale.

Nanofabrication Fabrication of structures with dimensions measured in nanometers.

Nanoparticle A small object that behaves as a whole unit with respect to its transport and properties, sized between 1 and 100 nanometers.

Nanopharmaceuticals Nanosized drug delivery systems that can be used to create a new combination drug.

Nanoporous materials Consist of a regular organic or inorganic framework supporting a regular, porous structure. The size of the pores is generally 100 nanometers or smaller.

PCR Polymerase chain reaction, a biochemical technology in molecular biology to amplify a single or a few copies of a piece of DNA across several orders of magnitude, generating thousands to millions of copies of a particular DNA sequence.

Peptide nucleic acids (PNA) Artificially synthesized polymer similar to DNA or RNA, used in molecular biology procedures, diagnostic assays and antisense therapies.

PE Polyethylene, a plastic polymer.

Personalized medicine Medical model that proposes the customization of healthcare – with medical decisions, practices, and/or products being tailored to the individual patient.

PHA Polyhydroxyalkanoates, linear polyesters produced in nature by bacterial fermentation of sugar or lipids.

Phage Virus that infects and replicates within bacteria.

Phase transition The transformation of a thermodynamic system from one phase or state of matter to another, most commonly used to describe transitions between solid, liquid and gaseous states of matter.

Piezo-resistive effect Describes change in the electrical resistivity of a semiconductor when mechanical stress is applied.

Plasmonic nanoparticles Particles whose electron density can couple with electromagnetic radiation of wavelengths that are far larger than the particle due to the nature of the dielectric-metal interface between the medium and the particles.[2] They exhibit interesting scattering, absorbance, and coupling properties based on their geometries and relative positions.

Point-of-care diagnostics Medical testing at or near the site of patient care.

Polymer vesicles Nano- to micrometer sized polymeric capsules with a bilayered membrane.[3]

PP Polypropylene, a thermoplastic polymer.

Process analytical technology (PAT) Defined by the United States Food and Drug Administration (FDA) as a mechanism to design, analyze, and control pharmaceutical manufacturing processes through the measurement of Critical Process Parameters which affect Critical Quality Attributes.

Protein engineering Process of developing useful or valuable proteins.

PVA Polyvinyl alcohol, a water-soluble synthetic polymer.

PVC Polyvinyl chloride, a plastic polymer.

Quantum dot Semiconductor whose excitons are confined in all three spatial dimensions. The electronic properties of these materials are intermediate between those of bulk semiconductors and of discrete molecules.

Solar Cell also called a photovoltaic cell, an electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

Stem cell therapy Intervention strategy that introduces new adult stem cells into damaged tissue in order to treat disease or injury.

Supercapacitors Family of electrochemical capacitors which don’t have a conventional solid dielectric, bridging the gap between conventional capacitors and rechargeable batteries. They have the highest available capacitance values per unit volume and the greatest energy density of all capacitors.

Surface Acoustic Wave (SAW) Acoustic wave traveling along the surface of a material exhibiting elasticity.

Surface plasmon resonance Collective oscillation of electrons in a solid or liquid stimulated by incident light.

Synthetic biology Design and construction of biological devices and systems for useful purposes.

Thin film A layer of material ranging from fractions of a nanometer (monolayer) to several micrometers in thickness.

Transmembrane protein Protein that goes from one side of a membrane through to the other side of the membrane.

XNA Xeno nucleic acid, a synthetic alternative to the natural nucleic acids DNA and RNA as information-storing biopolymer.

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FUNDING

The organizers gratefully acknowledge project funding by

- Klaus-Tschira-Stiftung
- LMU Munich
- Suisse Nanoscience Institute
- and FWF (Austria), FWO (Belgium), DFG (Germany), NWO (The Netherlands), The Research Council of Norway, Swiss National Science Foundation, BBSRC and EPSRC (United Kingdom) within the **EUROCORES Programme** 'Synthetic Biology: Engineering Complex Biological Systems' of the **European Science Foundation**.

IMPRINT

Center for NanoScience (CeNS)
Ludwig-Maximilians-Universität München
Geschwister-Scholl-Platz 1
D-80539 Munich, Germany

Editing
Dr. Susanne Hennig

Layout and Typesetting
Sebastian Lehnert, Munich
→ www.deskism.com

Printing
Eder Druck, Dachau

PHOTO CREDITS

Cover: Steve Jurvetson, NanoTemper Technologies, Christian Westermeier, William Thielicke, Bastian Ruehle; Inner cover: Audrey Fischer, SNI; **page 9:** Steve Jurvetson; **page 11:** Effeietsanders, Alf Mertens; **page 13:** Joydeep; **page 15:** DFID – UK Department for International Development; **page 17:** USAID; **page 19:** William Thielicke; **page 21:** F1jmm; **page 26:** Audrey Fischer, SNI, Gino Günzburger

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EUROPEAN SCIENCE FOUNDATION

EUROCORES Programme
European Collaborative Research