FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA

A TECHNOLOGY TEASER

NANOTECH SPONGES

ISTITUTO ITALIANO DI TECNOLOGIA

Released on January 2015

NEW MATERIALS

Istituto Italiano di Tecnologia – Mission and History

The Foundation is intended to promote Italy's technological development and advanced education, consistent with national policies for scientific and technological development, thus strengthening the national production system.

For this purpose, the Foundation:

- helps and accelerates the development, within the national research system, of scientific and technological skills able to facilitate state of the art technological advancements of the national production system;

- develops innovative methods and know-how, in order to facilitate new high-level practices and positive competitive mechanisms in the field of national research;

- promotes and develops scientific and technological excellence, both directly, through its multi-disciplinary research laboratories, and indirectly, through a wide collaboration with national and international laboratories and research teams;

- carries out advanced training programs as a part of wider multi-disciplinary projects and programs;

- fosters a culture based on sharing and valuing results, to be used in order to improve production and for welfare-related purposes, both internally and in relation to the entire national research system;

- creates technological understanding about components, methods, processes and techniques to be used for the implementation and interconnection of innovative products and services, in strategic areas for the competitiveness of the national production system;

- pools research scientists operating in various research institutes and establishes cooperation agreements with high-level, specialized centers;

- promotes interactions between basic research and applied research facilities, encouraging experimental development;

- spreads transparent, merit-based selection mechanisms for research scientists and projects, in compliance with globally approved and established criteria.

CONTENTS

EXECUTIVE SUMMARY

Oil and fuel spills released during industrial accidents or oil tankers and ships sinking, toxic chemicals and heavy metals released to rivers and sea by industrial sites are some of the unfortunately many catastrophic events for the marine and aquatic ecosystems. To avoid such environmental disasters, immediate polluted water purification and long-term water preservation are essential. Polymeric nanocomposite foams are developed at IIT using a combination of nanoparticle solutions and polymers of desired properties, in order to be used for cleaning water from oil, petrol, dyes, or heavy metal ion contaminants.

These technologies represent a unique chance for companies active in water treatment or pollution control fields and willing to branch out into different market areas. IIT assets appear well positioned for an out-licensing strategy, providing the licensee partner with the ability to take care of the late stage development, CE certification, scale-up and production process. The licensee should guarantee a high probability of market success based on consolidated marketing & distribution organization. A typical licensing strategy based on entry fee and subsequent royalties on net sales can be envisaged.

INTELLECTUAL PROPERTY

PCT International Application #
PCT/IB2013/061287 - 23 December 2013
Priority Application #
TO2012A001159 – 28th December 2012
Applicant
Fondazione Istituto Italiano di Tecnologia
International Publication # and date
WO 2014/102708 - 03 July 2014
Inventors
Despina FRAGOULI, Elisa MELE, Athanassia ATHANASSIOU
Title
Process for producing polymer foams

Short Description
The present invention relates to a process for producing expanded polymeric materials or articles or polymer foams, by using hydrogel pearls as a porosity-generating template. Said hydrogel pearls comprise substances, macromolecules and/or precursor compounds of nanoparticles which play a functional activity, particularly therapeutic activity, of chemical-physical processes, of biological, chemical and environmental testing, of water purification, oil and other liquids.

Priority Application #
IT 102016000022066 – 2nd March 2016
Applicant
Fondazione Istituto Italiano di Tecnologia
International Publication # and date
TBD – 3rd September 2017
Inventors
Javier PINTO-SANZ, Despina FRAGOULI, Athanassia ATHANASSIOU, Roberto CINGOLANI
Title
Reusable absorbent foams, production method and use for the in-situ remediation of oil spills

IIT TECHNOLOGY

The polymer foams or nanocomposite polymer foams that are the subject of IIT invention WO 2014/102708A2 find application in the following technical fields:

- **Biological applications**, in which the foams obtained may be used as scaffolds, artificial implants or for the immobilization of cells, functional proteins or other macromolecules. Each single cell of the foam can act as a reaction chamber for biological reactions, multiplex assays and cellular encapsulation. In addition, it is possible to produce integrated microdevices from the polymer foams to guide the cell growth, since the exchange of nutrients and gases is promoted by the porosity of the foam. Some materials proposed for such applications may comprise elastomeric foams, biodegradable foams obtained from natural polymers, for instance starch, expanded natural rubber bearing nanocomposite pores or pores with functional ligands. Some of these foams may have particular optical properties, such as transparency, which is of interest for the optical revelation of biological events that take place inside or on the surface of the foam;
- **Chemical analyses** of waters or other liquids. In this case, the specific functionalization of predefined cells of the foam may induce the explicit binding of chemical substances thereon, facilitating the subsequent analysis;
- **Environmental applications**, for example for water purification. The polymer foams may have functional nanocomposite pores, on the walls of which are anchored metal nanoparticles, such as Au, Pt and Ag, which act as filters, trapping toxic and harmful substances present in the water passing therethrough. In addition, these types of foams may be used for water-oil separations due to the functionalization appropriateness of their mass and surface. For the purpose of obtaining this result, the use of Teflon or other highly hydrophobic polymer particles on the surface or of iron oxide or of other oleophilic nanoparticles in the bulk may transform the foams into superhydrophobic oil-absorbing foams, preventing water from penetrating, but efficiently absorbing oil. Iron oxide or other magnetic oleophilic nanoparticles make the foams magnetic, and as such a weak magnet can push the floating foams toward the areas polluted with oil/petroleum, where the foams can act efficiently to bring about a cleaning action, by absorbing the oil/petroleum. Such a treatment may also be extended to other types of foams (for example polyurethane foams);
- **Purification of oily substances** such as glycerol, petroleum, etc., separating these substances from water, excess moisture, solvents, etc.;
- **Production of miniaturized elements**. Nanocomposite foams with cells mainly functionalized with metal particles or emitters or with emitting dyes may be used for the production of miniaturized elements that are useful in the optical and plasmonics fields.

IIT interests and further developments concentrate in the field of **Environmental applications** and, particularly, in **Water Purification**.

Smart Foams for Water Purification

Oil and fuel spills released during industrial accidents or oil tankers and ships sinking (Figure 1), toxic chemicals and heavy metals released to rivers and sea by industrial sites (Figure 2) are some of the unfortunately many catastrophic events for the marine and aquatic ecosystems. To avoid such environmental disasters, immediate polluted water purification and long-term water preservation are essential. Polymeric nanocomposite foams are developed at IIT using a combination of nanoparticle

solutions and polymers of desired properties, in order to be used for cleaning water from oil, petrol, dyes, or heavy metal ion contaminants.
The foams can be either fabricated using simple template, gas, or chemical techniques, or in many cases also already existing foams appropriately modified can be used. The IIT technologies developed for this purpose are summarized below.

Figure 1. Oil spills from industrial accidents or ships sinking

Figure 2. Toxic chemicals released from industrial sites

Magnetoactive superhydrophobic and superoleophilic foams for water oil separation

Polyurethane foams are rendered superhydrophobic and simultaneously oil absorbing, and can be used for the purification of oil contaminants from water. The polyurethane foams are loaded with colloidal superparamagnetic iron oxide nanoparticles throughout their volume (internal pores) and are covered only onto their surfaces with Teflon submicrometer particles (Figure 3).

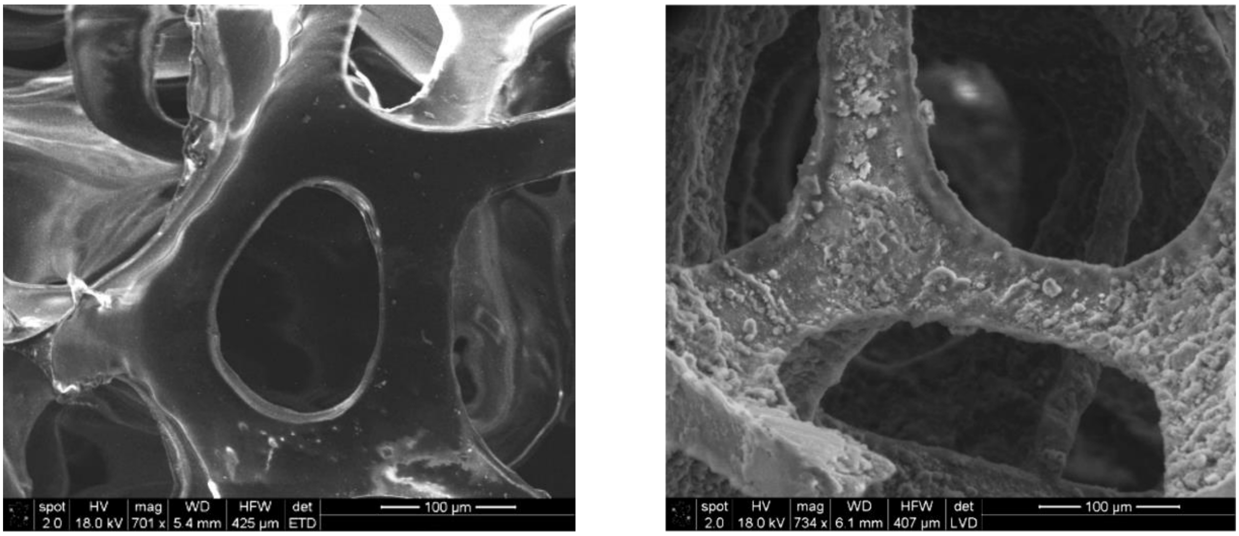

Figure 3. A polyurethane foam under electronic microscope before (left) and after (right) the functionalization

Figure 4.A jet of water repelled by the functionalized polyurethane foam due to its treatment by superhydrophobic particles

The treated foams totally repel the water (Figure 4) and can absorb more than 13 times their weight in oil so they can efficiently separate oil from water (Figure 5).

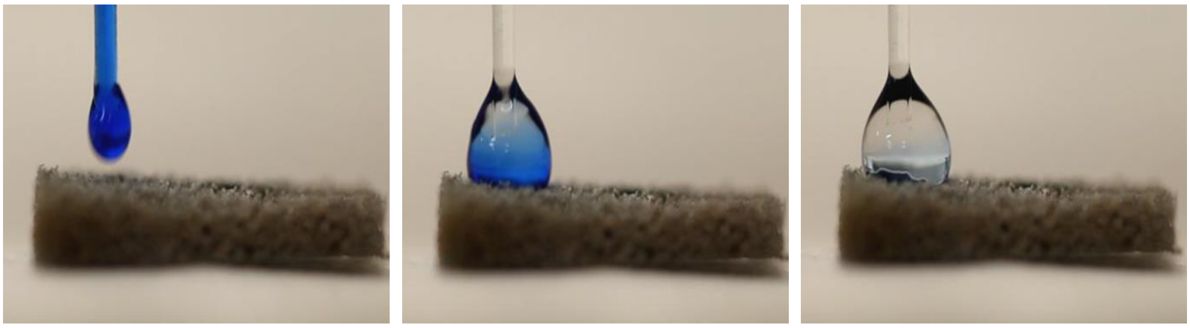

Figure 5. Foam treatment with oleophilic magnetic nanoparticles renders it oil absorbing; after the deposition of a mixed oil-water drop (oil is blue) onto the functionalized foam, all the oil is absorbed and the water remains clean on the surface.

In addition to the water-repellent and oil absorbing capabilities, the functionalized foams exhibit also magnetic responsivity, so they can be moved to the oil spill with magnets by a certain distance (Figure 6).

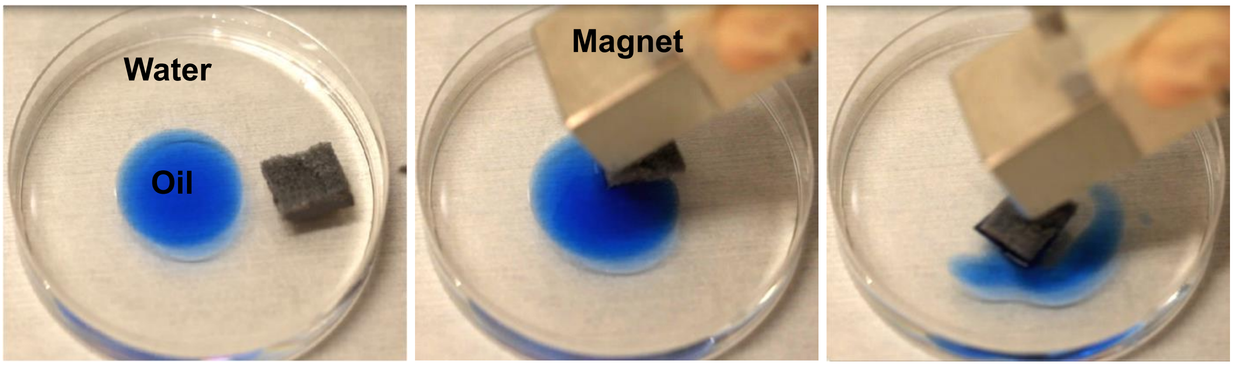

Figure 6. The foam is moved from a distance with a magnet towards the oil drop and absorbs it leaving the water clean

Foams able to entrap heavy metal ions dispersed in water

Polymeric foams, fabricated using very simple template methods, initially get chemically modified with organic surfactants in order to become highly water absorbing. Then, the pores' and the outer foams' surfaces become decorated with functional nanoparticles (i.e. ZnSe and CuS nanoparticles), able to interact with heavy metal ions present in water, by cation exchange mechanisms between the nanocomposite foams and the polluted water or by ion entrapment (Figure 7). The fabricated foams can be used for the detection and removal of Pb, Hg and other heavy metal ions from water.

Figure 7. Elastomeric foam before (white), after ZnSe treatment (yellow), and after removal of Pb^{2+} ions from water (dark brown)

Foams with functional nanoparticles deposited exclusively in the pores surface for selective pollutant entrapment

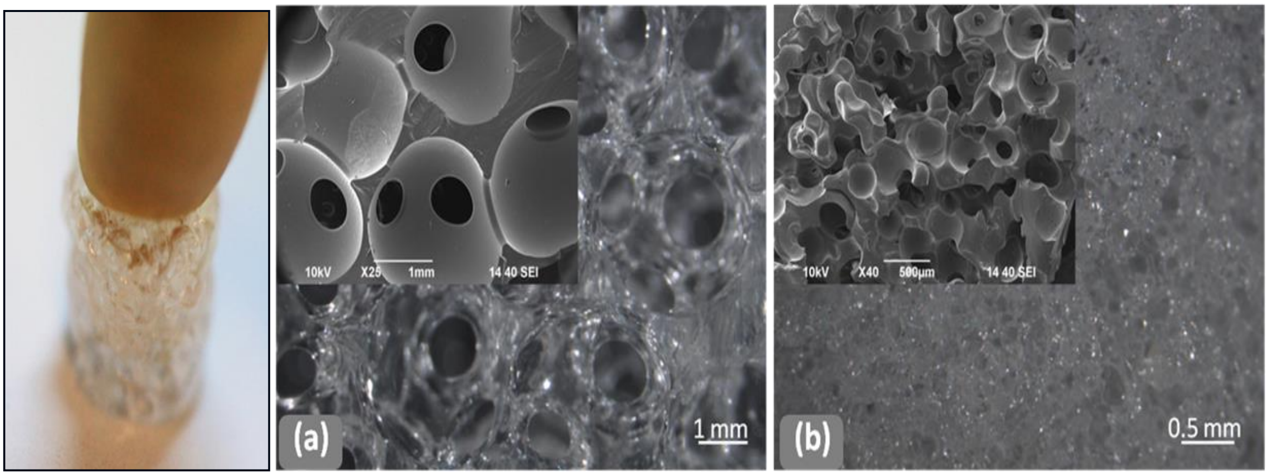

Figure 8. Elastomeric foams of various pore sizes created after the removal of calcium alginate microbeads incorporated in the elastomer bulk during its development.

Flexible elastometric foams with tunable pore sizes have been developed by an IIT patented technology. In particular, spherical microbeads of calcium alginate produced by microfluidic drop generators are incorporated closely packed into the elastomer material during its cross linking. After the solidification of the elastomer the calcium alginate microbeads are removed by a simple procedure (sacrificial template) leaving behind the elastomeric foams (Figure 8). During the formation of calcium alginate microbeads, metallic precursors can also get trapped in them. These precursors are subsequently released into the elastomeric matrix during its cross-linking resulting in the controlled localized formation of nanoparticles onto the surface of the pores of the polymer foam (Figure 9). Such foams can be used in localized reactions for environmental applications (specific pollutants entrapment) but also in biological applications (scaffolds and artificial implants).

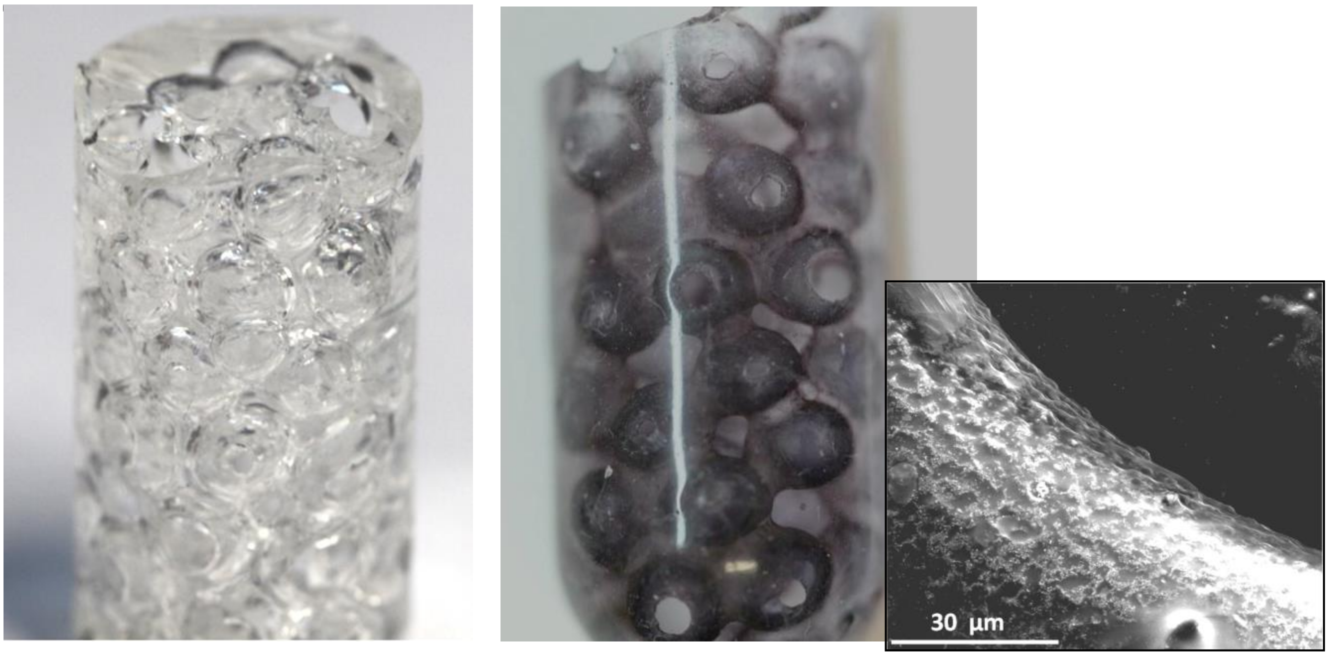

Figure 9. Pictures of elastomeric foams without nanoparticles (left) and with nanoparticles onto the surface of its pores (middle). The picture on the right shows the surface of a pore decorated by nanoparticles under the electronic microscope

MARKET ANALYSIS

Based on IIT invention described in published WO 2014/102708, internal documentation and know-how on the technology, and related literature publications by the inventors and competitors, the **Market of Adsorbents for Water Pollution Control** has been identified as the major reference marketplace and has been analyzed for its current dimension and future trends through a web search-based retrieval of specific information. However, another and greater-in-size relevant market for the IIT Technology described herein is the **Water Treatment Products Market**. For both markets, key players have been identified and their websites have been reported. Providing clean and affordable water to meet human needs is a grand challenge of the 21st century. Worldwide, water supply struggles to keep up with the fast growing demand, which is exacerbated by population growth, global climate change, and water quality deterioration. Figure 10 below shows major categories, examples, human sources and harmful effects of water pollutants.

INFECTIOUS AGENTS
Examples: Bacteria, viruses, protozoa, and parasitic worms.
Major Human Sources: Human and animal wastes.
Harmful Effects: Disease.

OXYGEN-DEMANDING WASTES
Examples: Organic waste such as animal manure and plant debris that can be decomposed by aerobic (oxygen-requiring) bacteria.
Major Human Sources: Sewage, animal feedlots, paper mills, and food processing facilities.
Harmful Effects: Large populations of bacteria decomposing these wastes can degrade water quality by depleting water of dissolved oxygen. This causes fish and other forms of oxygen-consuming aquatic life to die.

INORGANIC CHEMICALS
Examples: Water-soluble: (1) acids, (2) compounds of toxic metals such as lead (Pb), arsenic (As), selenium Se), and (3) salts such as sodium chloride (NaCl) in ocean water and fluorides (F^-) found in some soils.
Major Human Sources: Surface runoff, industrial effluents, and household cleansers.
Harmful Effects: Can: (1) make fresh water unusable for drinking or irrigation, (2) cause skin cancers and crippling spinal and neck damage (F^-), (3) damage the nervous system, liver, and kidneys (Pb and As), (4) harm fish and other aquatic life, (5) lower crop yields, and (6) accelerate corrosion of metals exposed to such water.

ORGANIC CHEMICALS
Examples: Oil, gasoline, plastics, pesticides, cleaning solvents, detergents.
Major Human Sources: Industrial effluents, household cleansers, surface runoff from farms and yards.
Harmful Effects: Can: (1) threaten human health by causing nervous system damage (some pesticides), reproductive disorders (some solvents), and some cancers (gasoline, oil, and some solvents) and (2) harm fish and wildlife.

PLANT NUTRIENTS
Examples: Water-soluble compounds containing nitrate (NO_3^-), phosphate (PO_4^{3-}), and ammonium (NH_4^+) ions.
Major Human Sources: Sewage, manure, and runoff of agricultural and urban fertilizers.
Harmful Effects: Can cause excessive growth of algae and other aquatic plants, which die, decay, deplete water of dissolved oxygen, and kill fish. Drinking water with excessive levels of nitrates lowers the oxygen-carrying capacity of the blood and can kill unborn children and infants ("bluebaby syndrome").

SEDIMENT
Examples: Soil, silt.
Major Human Sources: Land erosion.
Harmful Effects: Can: (1) cloud water and reduce photosynthesis, (2) disrupt aquatic food webs, (3) carry pesticides, bacteria, and other harmful substances, (4) settle out and destroy feeding and spawning grounds of fish, and (5) clog and fill lakes, artificial reservoirs, stream channels, and harbors.

RADIOACTIVE MATERIALS
Examples: Radioactive isotopes of iodine, radon, uranium, cesium, and thorium.
Major Human Sources: Nuclear and coal-burning power plants, mining and processing of uranium and other ores, nuclear weapons production, natural sources.
Harmful Effects: Genetic mutations, miscarriages, birth defects, and certain cancers.

HEAT (THERMAL POLLUTION)
Examples: Excessive heat.
Major Human Sources: Water cooling of electric power plants and some types of industrial plants. Almost half of all water withdrawn in the United States each year is
for cooling electric power plants.
Harmful Effects: Lowers dissolved oxygen levels and makes aquatic organisms more vulnerable to disease, parasites, and toxic chemicals. When a power plant first opens or shuts down for repair, fish and other organisms adapted to a particular temperature range can be killed by the abrupt change in water temperature-known as *thermal shock.*

Figure 10. Major categories of water pollutants

The need for technological innovation to enable integrated water management cannot be overstated. Nanotechnology holds great potential in advancing water and wastewater treatments to improve treatment efficiency as well as to augment water supply through safe use of unconventional water sources. According to the Chemical Engineering Department of Sardar Vallabhbhai National Institute of Technology (http://www.slideshare.net/AshishKavaiya/ashish-kavaiyau10-ch010-ppt), water treatments by nanotechnology can be further distinguished into:

1. Nanofiltration (NF)
2. Catalytic degradation of water pollutants
3. Adsorption of pollutants
4. Magnetic nanoparticles
5. Nanosensors

1. NF membranes are pressure-driven membranes with properties between those of reverse osmosis and ultrafiltration membranes and have pore sizes between 0.2 and 4 nm. NF membranes are used in water treatment for drinking water production or wastewater treatment. NF membranes have been shown to remove turbidity, microorganisms and inorganic ions such as Ca and Na. They are used for softening of groundwater (reduction in water hardness), for removal of dissolved organic matter and trace pollutants from surface water, for wastewater treatment (removal of organic and inorganic pollutants and organic carbon) and for pretreatment in seawater desalination.

2. Nanoparticles serve as catalysts that chemically degrade pollutants. An example are nano TiO_2 particles for degrading organic as well inorganic pollutants. In water, photo-oxidation occurs primarily through hydroxyl radicals. Because TiO_2 requires ultraviolet light for excitation, it has been sensitized to visible light by dyes, through incorporation of transition metal ions or by doping with nitrogen. Nanoscale zerovalent iron (NZVI) and bimetallic iron detoxify organic and inorganic pollutants in aqueous solutions. NZVI can reduce not only organic contaminants but also the inorganic anions nitrate, which is reduced to ammonia, perchlorate, selenate, arsenate and chromate. Granular ZVI in the form of reactive barriers has been used for many years at numerous sites all over the world for the remediation of organic and inorganic contaminants in groundwater.

3. Adsorbents, for example activated carbon and ion-exchange resins, are widely used in water treatment and purification to remove organic and inorganic contaminants. The unique structure and electronic properties of some nanoparticles can make them powerful adsorbents. The removal of metals and other inorganic ions, mainly nanosized metal oxides but also natural nanosized clays have been investigated. Chemically modified nanomaterials have also attracted a lot of attention, especially nanoporous materials dues to their exceptionally high surface area.

4. Magnetic nanoparticles offer advantages over non-magnetic nanoparticles because the pollutants can easily be separated from water using a magnetic field. Separation using magnetic gradients, the so-called high gradient magnetic separation (HGMS), is a process widely used in medicine and other processing. This technique allows one to design processes where the particles not only remove compounds from water but also can easily be removed again and then be recycled or regenerated. This approach has been proposed with magnetite (Fe_3O_4), maghemite (g-Fe_2O_3) and jacobsite ($MnFe_2O_4$) nanoparticles for removal of chromium (VI) from wastewater.

5. Nanosensors are any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world. Nanosensors for the detection of contaminants and pathogens can improve health, maintain a safe food and water supply, and allow for the use of otherwise unusable water sources. New sensor technology combined with micro- and nanofabrication technology is expected to lead to small, portable, and highly accurate sensors to detect chemical and biochemical parameters. BioFinger is

developing a handheld device that incorporates nano- and microcantilevers on a microchip. The system could be used to analyze chemicals and bacteria in water.

Figure 11 below shows the products on the market/in development using nanotechnologies.

Product	How it works	Importance	Developers
Nanorust to remove arsenic	Magnetic nanoparticles of iron oxide suspended in water bind arsenic, which is then removed with a magnet	India, Bangladesh and other developing countries suffer thousands of cases of arsenic poisoning each year, linked to poisoning of wells.	Rice University, US
Desalination membrane	A combination of polymers and nanoparticles that draws in water ions and repels dissolved salts.	Already on the market, this membrane enables desalination with lower energy costs than reverse osmosis.	University of California, Los Angeles and LG NanoH2O, US
Nanofiltration Membrane	Membrane made up of polymers with a pore size ranging from 0.1-10nm	Field tested to treat drinking water in China and desalinate water in Iran. Using this membrane requires less energy than reverse osmosis.	Sachen Industrial Ltd., China
Nanomesh waterstick	A straw like filtration device that uses carbon nanotubes played on a flexible, porous material.	The waterstick cleans the water as it is drunk. Doctors in Africa are using a prototype and the final product is said to be available at an affordable cost in developing countries.	Seldon Technologies, US
World Filter	Filter using a nanofiber layer, made up of polymers, resins, ceramics and other materials that remove contaminants.	Designed specifically for the household or community level use in developing countries. The filters are effective, easy to use and require no maintenance.	KX Technologies, US
Pesticide Filter	Filter using nanosilver to adsorb and then degrade three pesticides commonly found in the Indian water supplies.	Pesticides are often found in the developing countries water supply. This pesticide filter can provide a typical Indian household with 6000 liters of clean water in one year.	Indian Institute of Technology, Chennai, India and Eureka Forbes Ltd., India.

Figure 11. Products on the market/in development using nanotechnologies

In Table 1 below, taken from the review: *"Applications of nanotechnology in water and wastewater treatment"* by X. Qu et al. (http://www.ncbi.nlm.nih.gov/pubmed/23571110), current and potential applications of nanotechnology in water and wastewater treatment are presented (**DOI**: 10.1016/j.watres.2012.09.058).

Table 1 – Current and potential applications of nanotechnology in water and wastewater treatment.			
Applications	Representative nanomaterials	Desirable nanomaterial properties	Enabled technologies
Adsorption	Carbon nanotubes	High specific surface area, highly assessable adsorption sites, diverse contaminant-CNT interactions, tunable surface chemistry, easy reuse	Contaminant preconcentration/detection, adsorption of recalcitrant contaminants
	Nanoscale metal oxide	High specific surface area, short intraparticle diffusion distance, more adsorption sites, compressible without significant surface area reduction, easy reuse, some are superparamagnetic	Adsorptive media filters, slurry reactors
	Nanofibers with core–shell structure	Tailored shell surface chemistry for selective adsorption, reactive core for degradation, short internal diffusion distance	Reactive nano-adsorbents
Membranes and membrane processes	Nano-zeolites	Molecular sieve, hydrophilicity	High permeability thin film nanocomposite membranes
	Nano-Ag	Strong and wide-spectrum antimicrobial activity, low toxicity to humans	Anti-biofouling membranes
	Carbon nanotubes	Antimicrobial activity (unaligned carbon nanotubes)	Anti-biofouling membranes
		Small diameter, atomic smoothness of inner surface, tunable opening chemistry, high mechanical and chemical stability	Aligned carbon nanotube membranes
	Aquaporin	High permeability and selectivity	Aquaporin membranes
	Nano-TiO_2	Photocatalytic activity, hydrophilicity, high chemical stability	Reactive membranes, high performance thin film nanocomposite membranes
	Nano-magnetite	Tunable surface chemistry, superparamagnetic	Forward osmosis
Photocatalysis	Nano-TiO_2	Photocatalytic activity in UV and possibly visible light range, low human toxicity, high stability, low cost	Photocatalytic reactors, solar disinfection systems
	Fullerene derivatives	Photocatalytic activity in solar spectrum, high selectivity	Photocatalytic reactors, solar disinfection systems
Disinfection and microbial control	Nano-Ag	Strong and wide-spectrum antimicrobial activity, low toxicity to humans, ease of use	POU water disinfection, anti-biofouling surface
	Carbon nanotubes	Antimicrobial activity, fiber shape, conductivity	POU water disinfection, anti-biofouling surface
	Nano-TiO_2	Photocatalytic ROS generation, high chemical stability, low human toxicity and cost	POU to full scale disinfection and decontamination
Sensing and monitoring	Quantum dots	Broad absorption spectrum, narrow, bright and stable emission which scales with the particle size and chemical component	Optical detection
	Noble metal nanoparticles	Enhanced localized surface plasmon resonances, high conductivity	Optical and electrochemical detection
	Dye-doped silica nanoparticles	High sensitivity and stability, rich silica chemistry for easy conjugation	Optical detection
	Carbon nanotubes	Large surface area, high mechanical strength and chemical stability, excellent electronic properties	Electrochemical detection, sample preconcentration
	Magnetic nanoparticles	Tunable surface chemistry, superparamagnetism	Sample preconcentration and purification

Adsorption appears the main principle underlining the IIT technology. Adsorbents are materials that sorb fluids and dissolve solids onto their surfaces. Adsorbents work by creating a layer of adsorbate on the surface through adhesion. They are used for various industrial and other applications including:

- Process Industries
- **Water Purification**

- Air Separation
- Others

Broadly, adsorbents are segmented into:

- Zeolite
- Activated Carbon
- Silica Gel
- Alumina
- Clay
- Metal Oxide
- Other segments

Adsorbents are increasingly being used to decrease the pollution and reduce contamination levels both in air and water that is caused during various industrial processes. Accordingly to the e-book published in May 2013 by ResearchnMarkets consultancy firm and titled: "*Applications of Adsorbents for water Pollution Control*" (http://www.researchandmarkets.com/reports/2528621/application_of_adsorbents_for_water_pollution) among various water and wastewater treatment technologies, the adsorption process is considered better because of lower cost, simple design and easy operation. Activated carbon (a universal adsorbent) is generally used for the removal of diverse types of pollutants from water and wastewater. Research is now being directed towards the modification of carbon surfaces to enhance its adsorption potential towards specific pollutants. However, widespread use of commercial activated carbon is sometimes restricted especially in developing or poor countries due to its higher costs. Attempts are therefore being made to develop inexpensive adsorbents utilizing abundant natural materials, agricultural and industrial waste materials. Use of waste materials as low-cost adsorbents is attractive due to their contribution in the reduction of costs for waste disposal, therefore contributing to environmental protection.

Accordingly to the MarketsnMarkets report published in December 2013 and titled: "*Adsorbents Market by Types (Molecular Sieves, Activated Carbon, Silica Gel, Activated Alumina, Clay, and Others), Applications (Petroleum Refining, Chemicals/Petrochemicals, Gas Refining, Water Treatment, Air Separation & Drying, Packaging, and Others) & Geographies (North America, Europe, APAC and ROW) - Global Trends and Forecasts to 2018*" (http://marketpublishers.com/report/chemicals_petrochemicals/adsorbents-market-by-types-molecular-sieves-activated-carbon-silica-gel-activated-alumina-clay-n-others-applications-petroleum-refining-chemicalspetroch.html), in 2012 the value of the overall adsorbents market was equal to USD 2.6 billion; **this market is anticipated to register a 6.1% CAGR in the offing, and it will likely climb to USD 3.8 billion by 2018.**

Air separation and drying, oil and gas refining, and **industrial water treatment** are the most popular applications of adsorbents. North America captures the commanding share of the worldwide market, followed by Asia-Pacific. Asia-Pacific is primed to become the top adsorbents market in volume terms by 2018. Rapid industrialization, mainly in the emerging economies of China and India, has been one of the major factors driving the global adsorbent sales. Adsorbents are widely used for removing and control trace contaminants from various industrial processes such as producing low sulfur fuels. Adsorbents are extensively used for a wide range application ranging from insulating glass windows to removal of mercury in a large scale natural gas/crude oil wellhead. Adsorbents are an integral part of any process used to manufacture modern day specialized product.

Growth of major end use industries such as water and air treatment, chemicals and petrochemicals mainly in Asia Pacific, Middle East and Latin America has been boosting the demand for adsorbents in the past and this trend is expected to continue over the next decade. In addition, growing environmental concerns regarding hazards caused due to waste water has been prompting regulatory bodies across various nations to mandate the use of adsorbents. The stringent regulatory norms mainly in the US and Europe to disinfect both water and air have been boosting the demand for adsorbents. However, the availability and high price associated with the procurement of raw materials for some specific adsorbents have been hindering the market growth.

Silica gel is one of the most widely used adsorbent mainly in the packaging industry. Silica gel exhibits good adsorption characteristics which prevents the formation of moisture in electrical and electronic goods. Asia Pacific is one of the leading consumer and producer for adsorbents. Owing to the growth of major end use industries in the region, major adsorbents manufacturers have been focusing on shifting and opening up their manufacturing bases in Asia Pacific countries. Countries such as India and China not only provides the participants an attractive demand centre but also helps in achieving cost efficiency during the production of adsorbents owing to cheap labor and government support in terms of tax benefits and tax holidays.

Enforcement of government regulations for industrial and municipal wastewater treatment is one of the major drivers in this market. Adsorbents are being extensively used for treating wastewater and removing heavy metal impurities such as lead, copper, cadmium, and chromium. With governments worldwide aiming to reduce groundwater contamination by wastewater, these regulations will benefit the growth of the market.

Analysts from ReportsnReports in the report titled: *"Global Adsorbents Market 2015-2019"* published in December 2014 by Infiniti Research Ltd., forecast **the global adsorbent market will grow at a CAGR of 6.34% over the period 2014-2019** (http://www.reportsnreports.com/reports/319508-global-adsorbents-market-2015-2019.html), well in line with the previously mentioned report by MarketsnMarkets.

Some more information are available for the market sub-segment that identifies inorganic nanoporous and microporous adsorbents as MarketResearch firm published in 2012 its report titled: "Global Market for Inorganic Nanoporous and Microporous Adsorbents" (http://www.marketresearch.com/BCC-Research-v374/Global-Inorganic-Nanoporous-Microporous-Adsorbents-6948680/). The North American market for inorganic nanoporous and microporous adsorbents reached USD 2.4 billion in 2012 and it will further grow to USD 2.9 billion by 2017, at a compound annual growth rate (CAGR) of 4.3%. The zeolite segment reached USD 1.3 billion in 2012 and it will further grow to USD 1.5 billion by 2017, at a compound CAGR of 3.5%. The granular activated carbon segment reached USD 517.5 million in 2012 and it will further grow to USD 642.2 million by 2017, at a compound CAGR of 4.4%.

More specific data relevant to the IIT technology come from the report published in August 2014 by ReportnReport and titled: *"Global Water Treatment Products Market 2014-2018"* (http://www.reportsnreports.com/Purchase.aspx?name=296060), that classifies the market into different segments based on: Technology (Filtration Systems, Chemicals and Membrane Systems), Geography (APAC Region, Americas and EMEA Region) and End-user (Industrial Consumers, Municipal Consumers and Other Consumers).

In this report, **the global water treatment products market is forecast to grow at a CAGR of 8.5% over the period 2013-2018**. Water treatment products refer to products that assist in removing the impurities from water. Various types of water such as sea water, ground water, municipal drinking water, and waste water can be treated using water treatment products. The wide variety of applications of water treatment products is one of the major reasons for an increase in demand for these products. Water treatment technologies are used to remove or destroy pesticide active ingredients and other pollutants in water, making it suitable for industrial as well as domestic use. Water treatment products are generally classified based on the type of technologies used for water treatment.

Commenting on the report, an analyst said: "One of the major trends observed in the market is the depletion of fresh water resources due to increase in the extraction of water from aquifers. The exhaustion of natural fresh water resources increases the need to recycle and reuse water through the adoption of various water treatment techniques, which will result in increased demand for water treatment products." According to the report, one of the major drivers in this market is the increase in water contamination. Various contaminants such as waste matter, mud, silt, algae, bacteria, and other germs lead to an increase in water contamination eventually leading to an increase in the need for water treatment. Further, the report states that one of the major challenges is appropriate management of wastewater treatment residues. Issues in managing harmful solid, semi-solid, and liquid residues generated after water treatment might hamper the growth of the market.

Another report titled *"Water Treatment Chemicals Market By Type (Coagulants & Flocculants, Corrosion Inhibitor, Scale Inhibitors, Biocides, Chelating Agents, Anti-foaming Agents, pH Adjusters & Others) & Application (Industrial & Municipal) - Global Trends & Forecasts to 2018"* says, geographically, Asia-Pacific is the key market for water treatment chemicals. It represents more than 35% of the market in terms of consumption. Rising demand for clean water in China and India is driving the Asia-Pacific as well as the global market for water treatment chemicals. China is the largest consumer for water treatment chemicals in the world.

COMPETITIVE SCENARIO

The following lists of key companies has been assembled from the different report sources mentioned above.

Leading companies in the Adsorbents for Water Pollution Control Market:

- Adcoa (USA, http://www.adcoa.net/)
- Advanced Emissions Solutions Inc. (USA, http://www.advancedemissionssolutions.com/)
- Akzonobel N.V. (The Netherlands, https://www.akzonobel.com/)
- Aquatech International Corp. (USA, http://www.aquatech.com/)
- Arcana Pool Systems (Germany, http://www.arcanapoolsystems.at/DE/)
- Ashland Inc. (USA, http://www.ashland.com/)
- Axens (France, http://www.axens.net/)
- Buckman Laboratories International Inc. (USA, https://buckman.com/)
- BWA Water Additives Ltd. (UK, http://www.wateradditives.com/)
- Cabot Corp. (USA, http://www.cabotcorp.com/)
- Calgon Carbon Corp. (USA, http://www.calgoncarbon.com/index.php)
- Carbochem Corp. (USA, http://carbochem.com/#/)
- Carbon Activated (UK, http://www.activatedcarbon.com/)
- Carbon Resources (USA, http://www.carbonresources.com/)
- Carus Corp. (USA, http://www.caruscorporation.com/)
- Ceca (France, a subsidiary of Arkema Group, http://www.cecachemicals.com/en/),
- Centroprojekt do Brasil (Brazil, http://www.centroprojekt-brasil.com.br/)
- Clariant (Switzerland, http://www.clariant.com/en/Corporate)
- Cortec Corp. (USA, http://www.cortecvci.com/Contacts/contacts.php)
- CPL Carbon Link Ltd. (UK, http://www.cplindustries.co.uk/content/cpl-carbon-link)
- Criterion Catalyst (USA, http://www.criterioncatalysts.com/)
- Danaher (USA, http://www.danaher.com/)
- Dedini Industrias de Base (Brazil, http://www.codistil.com.br/)
- Degremont SAS (France, http://www.degremont.com/en/homepage/)
- Donau Chemie (Austria, http://www.donau-chemie-group.com/)
- Doosan Heavy Industries & Construction (Korea, http://www.doosan.com/)
- Dow Chemical (USA, http://www.dow.com/)
- Enfil SA (Brazil, http://www.enfil.com.br/)
- Eureka Forbes (India, http://www.eurekaforbes.com/Company)
- Evoqua Water Technologies (USA, http://www.evoqua.com/en/Pages/default.aspx)
- Feralco Group AB (Sweden, http://www.feralco.com/page108-central-support.php)
- General Carbon (USA, http://generalcarbon.com/)

- GE Water and Process Technologies (USA, http://www.gewater.com/)
- Graver Technologies (USA, http://www.gravertech.com/)
- GSA Resources (USA, http://www.gsaresources.com/)
- Haycarb (Sri Lanka, http://www.haycarb.com/)
- Haztec (Brazil, http://www.haztec.com.br/solucoes-ambientais-completas/pt/)
- J.M. Huber (USA, http://www.huber.com/)
- Kao Corp. (Japan, http://www.kao.com/index_en.html)
- Kemira Oyj (Finland, http://www.kemira.com/en/Pages/default.aspx)
- Kureha Corp. (Japan, http://www.kureha.co.jp/en/0)
- Kurita Water Industries Ltd. (Japan, http://www.kurita.co.jp/english/)
- KX Technologies (USA, http://www.kxtech.com/)
- LG Chem (Korea, http://www.lgchem.com/global/main)
- LG NanoH2O (USA, http://www.nanoh2o.com/)
- Lonza Group Ltd. (Switzerland, http://www.lonza.com/)
- MeadWestvaco Corp. (USA, http://www.mwv.com/en-us/)
- Minerals Technologies Inc. (USA, http://www.mineralstech.com/)
- Mitsubishi Chemical Corp. (Japan, http://www.mitsubishichem-hd.co.jp/english/)
- Multisorb Technologies (USA, http://www.multisorb.com/)
- Nalco Holding (USA, http://www.nalco.com/)
- NanoPore Inc. (USA, http://www.nanopore.com/index.html)
- NeoZeo AB (Sweden, http://www.neo-zeo.com/)
- Nippon Rensui Co. (Japan, http://www.rensui.co.jp/en/index.html)
- Nucon International (USA, http://www.nucon-int.com/)
- Osaka Gas Chemicals (Japan, http://www.ogc.co.jp/e/)
- Perenne - Equipamentos e Sistemas de Água S.A (Brazil, http://www.perenne.com.br/)
- Plymouth Technology Inc. (USA, http://www.plymouthtechnology.com/)
- Porocel (USA, http://www.porocel.com/)
- PQ Corp. (USA, http://www.pqcorp.com/)
- Purolite Corp. (USA, http://www.purolite.com/RelId/33637/ISvars/default/Home.htm)
- ResinTech Inc. (USA, http://resintech.com/)
- Sachen Industrial Ltd. (China, http://www.sachen-china.com/)
- Seldon Technologies (USA, http://seldontech.com/)
- Sorbead India (India, http://www.sorbeadindia.com/)
- Teague Mineral Products (USA, http://www.teaguemineralproducts.com/)
- Tecitec (Brazil, http://www.tecitec.com.br/)
- Thermax Ltd. (India, http://www.thermaxindia.com/)
- TIGG Corp. (USA, http://www.tigg.com/),
- Tosoh organic chemicals Co. Ltd. (Japan, http://www.tosoh-organic.co.jp/en/)

- Toyobo Company (Japan, http://www.toyobo-global.com/)
- Tricat Group (USA, http://www.tricatgroup.com/)
- UOP, A Honeywell Company (USA, http://www.uop.com/)
- Veolia Water Solutions & Technologies (France, http://veoliawatertechnologies.com/en/)
- Watch Water USA (USA, http://www.watchwater.com/)
- W.R. Grace Construction (USA, https://grace.com/en-us)
- Wujin Fine Chemical Factory Co. Ltd. (China, http://www.wfcf.com/)
- Zeochem (Switzerland, http://www.zeochem.ch/dev/index.html)
- Zeolyst International (USA, http://www.zeolyst.com/home.aspx)

Absorbent polymers:

- Aculon Inc. (USA, http://www.aculon.com/)
- Apyron Technologies (USA, http://www.apyron.com/)
- Arkema SA (France, http://www.arkema.com/en/)
- BASF (Germany, http://www.hygiene.basf.com/)
- Chemtreat Inc. (USA http://www.chemtreat.com/)
- EVONIK Industries (Germany, http://corporate.evonik.com/en/Pages/default.aspx)
- Nippon Shokubai (Japan, https://www.shokubai.co.jp/en/)
- SNF Floerger Group (France, http://www.snf-group.com/0)
- Sumitomo Seika Chemicals (Japan, http://www.sumitomoseika.co.jp/english/)
- Yixing Danson Technology *(*China*,* http://www.chinadanson.com/en/company.asp)

Spill prevention, containment and control:

- New Pig (USA, https://www.newpig.com/)
- ENPAC (USA, http://www.enpac.com/)
- Spilldam Environmental Inc. (USA, http://www.spilldam.com/)
- ICEA (Italy, http://www.icea.it/)
- Ecork (Italy, http://www.ecork.eu/)
- Empteezy (Italy, http://www.empteezy.it/)
- Fosse Liquitrol (UK, http://www.fosseliquitrol.com/)
- Darcy Spillcare Manufacture (UK, http://www.darcy.co.uk/)

FOR FURTHER READING

- P. Calcagnile, D. Fragouli, I.S. Bayer, G.C. Anyfantis, L. Martiradonna, P.D. Cozzoli, R. Cingolani, A. Athanassiou.
  Magnetically driven floating foams for the removal of oil contaminants from water, ACS NANO, 2012, 6 (6), 5413-5419.
  DOI: 10.1021/nn3012948 (http://pubs.acs.org/doi/abs/10.1021/nn3012948).

- P. Calcagnile, D. Fragouli, I.S. Bayer, G.C. Anyfantis, A. Athanassiou.
  Magnetoactive superhydrophobic foams for oil-water separation. **Advances in Science and Technology**, 2013, 77, 159-164.
  DOI: 10.4028/www.scientific.net/AST.77.159
  (http://www.scientific.net/AST.77.159).

- P. Calcagnile, D. Fragouli, E. Mele, R. Ruffilli, A. Athanassiou.
  Polymeric foams with functional nanocomposite cells. **RSC Advances**, 2014, 4 (37), 19177-19182.
  DOI: 10.1039/c4ra00823e
  (http://pubs.rsc.org/en/content/articlelanding/2014/ra/c4ra00823e#!divAbstract).

CONTACTS @IIT

Fondazione Istituto Italiano di Tecnologia (IIT)
Via Morego 30 - 16163 Genova, Italy
Tel: +39 010 71781 - Fax: +39 010 720321
C.F. 97329350587 - P.I. 09198791007
Technology Transfer – technology.transfer@iit.it