INVESTIGA R&D&I 2018/2019

SPECIFIC WORK GUIDE ON"NANOTECHNOLOGY FOR THE RESOLUTION OF HUMANITY'S ENERGY AND ENVIRONMENTAL CHALLENGES"

Text byDr. Pedro A. Serena Domingo

October 2018

Introduction

Nanoscience, nanotechnology and new materials have been considered, as a whole, one of the five strategic lines of the previous editions of the Investiga R&D&I Program (http://www.programainvestiga.org/). This choice is due to the fact that these subjects have shaped up to be key research topics in the most developed countries in the world. To give a couple of examples, 18 years ago in the United States the National Nanotechnology Initiative (NNI, http://www.nano.gov/) was launched, whose purpose was to achieve that said country were a world leader in the application of nanotechnology in diverse sectors, while in the European Union, nanoscience and nanotechnology have been a strategic research axis both for the 7th Framework Programme and the Horizon 2020 Programme.In particular, within the H2020 program, nanotechnology is a key piece for the industrial development of Europe in this first half of the 21st century, forming a part of the Key Enabling Technologies (KETs)which have leapt from the laboratory to companies and which are starting to appear in a great many products. We will also mention China which, following the trail of countries like Japan and

South Korea, has burst upon the world research panorama and currently leads scientific production in these topics at the same time as it increases its position in the field of patents. One characteristic of nanotechnology is its transversal nature;that is to say that it can be applied to a great many sectors, which has made it possible for each edition of the Investiga R&D&I Program to be able to tackle a different aspect: nanotechnology in general, nanotechnology and its application in sports,the impact of nanotechnology in agriculture, food and cosmetics, nanorobots, the fascinating and versatile graphene, nanotechnology to wear, the relation between nanotechnology and the implementation of smart cities, nanotechnology and sustainable development, and finally nanomedicine. This document proposes an aspect of nanotechnology which enables expanding or completing some of the topics which have been dealt with in previous editions. In this edition, the proposed subject is the use of nanotechnology (through nanomaterials and nanodevices) to solve the serious environmental and energy problems which human beings have.

Both nanotechnology and the subject energy+environment are multidisciplinary topics of great extent, so it is evident that many meeting points between both topics are going to be found. The purpose of choosing this subject this year is to achieve that the participantsdelve into the fascinating world of nanotechnology, identifying its peculiarities, showing its huge potentialfor generating new materials and devices that can helpsolve problems which we human beings facerelated to the need to find cleaner energy sources,slowing down the deterioration which our species has caused the planet. The participant along these lines must make a general analysis of the proposed topic, detecting meeting points between nanotechnology and the energy+environment binome, and choosing just a few (one or two) which will be tackled more in-depth.

Moreover, another equally important aim is to make the participating students see that nanotechnology also has a less positive side, as occurs with every technology. Automobiles, chemical products and nuclear power plants are examples of technologieswhich have contributed progress to humankindbut which implicitly carry many risks, which we must manage adequately, in order to weigh up the benefits and risks and decide upon the way in which they must be used and the regulations they must be submitted to. Bearing in mind these aspects during the development of the work is an aspect which will be valued positively.

In short, it is a matter of taking advantage of the fascination evoked by the tiny in order to promote curiosity for science, increase knowledge about the technologies which are going to surround us in the middle-long term, and encourage the critical spirit of the participants, who will be the citizens of the future of our country, some of them as consumers and users, others as entrepreneurs, others as research scientists, and a few perhaps as political leaders.In the second section of this document, the main aspects which characterize nanotechnology are reviewed. The third section is devoted to outlining several ideas about the subject proposed in this edition of the Investiga R&D&I Program. The fourth section raises a series of questions and particular themes which can be used for debates in the classroomsand to participate in the Open Forum of the Investiga R&D&I Program. The ideas which areexchanged between the participants will be the seed for the papers which the students will develop later on. The fifth section provides some adviceabout the elaboration of the papers. The document ends with a small set of references which can be useful.

Nanoscience and Nanotechnology: key aspects.

What is "nanoscience"? In a simple way, "nanoscience" can be defined as the structured accumulation of interconnected knowledgewhich makes

it possible to understand how nature works when it is observed on a tiny scale, the so-called "nanoscale"; that is to say, when objects are observed with a size of a few nanometers and their properties are studied. By the way, a nanometer is a really small unit of length: 1 nanometer equals 0.001 micrometers or microns, 0.000001 millimeters, or 0.000000001 meters. The same chain of equivalences can be written using scientific notation:1 nm = 10^{-3}μm = 10^{-6} mm = 10^{-9} m. It is evident that the prefix "nano" (from the Greek "nanos", dwarf) is used to refer to small but ever so small things.

On the other hand "nanotechnology" goes beyond nanoscience, and aims to convert the basic knowledge which the latter provides us with in relation tothe new properties of the materials in order to improve the current goods and products or propose other radically new ones. In this way it is clear that nanotechnology essentially has to do with the application of knowledge which stems from nanoscience. The generation of knowledge requires great investments which can turn profits if said knowledgeis set into motion. The generation of knowledge is developed fundamentally at universities and research centers, while the application of knowledge will have to be developed at technology centers and companies.

It is often thought that nanoscience and nanotechnology are modern or almost futuristic terms, which we bump into in comics, films, novels or television series. However, they are not so new since nanoscience research has been carried out at research laboratoriesfor nearly fifty years now. Way back in 1959, Physics Nobel Prize winner Richard Feynman anticipated many of the concepts and instruments which are currently handled in this fascinating discipline. However, it is true that it has been the last 15-20 years when nanoscience and nanotechnology have experienced a spectacular boost by governments, institutions and

companies, which have realized their huge possibilities. I will mention as an examplethat the first initiative of great dimensions to promote nanotechnologywas launched in the United States and was called the"NationalNanotechnologyInitiative" (http://www.nano.gov/). This interest has led to huge investments with which new laboratories have been started, expert scientists and engineers in these subjects have been trained, prototypes and demonstrators have been made, etc. Given that the term "nanotechnology" is the one that has had the most impact on the media and on society, from nowon it will be the one used in this document to refer both to the basic aspects and the applied ones.

The nanoscale, which is also usually called "nanoworld", is a setting inhabited by different types of "nano-objects" and "nanostructures", among which we can include atoms, molecules, nanoparticles, carbon nanotubes, graphene, metal nanowires and semiconductors, DNA strands, proteins, ribosomes, viruses, etc. This "nanofauna" is interesting because it exhibits a series of phenomena which would not be demonstrated if their size were much larger. This is what gives everything "nano" a great added value with regards to the "micro" or the "macro" and that is why it is said that the "nano" is different. Why would there be interest in the small, from a technological standpoint, if there weren't a high added value?

But why do these new properties appear? There are several reasons. On the one hand, it is known that the atoms on surfaces behave differently to atoms which are found inside the object, since they have different surroundings. As an object becomes smaller and smaller, it is observed how the proportion of atoms on the surface becomes greater and greater. For example, in a nanoparticle of 100 nm in diameter, 1-2% of its atoms are on the surface, while in a nanoparticle of 3nm that percentage grows to approximately 60%. You can say that the 3 nm

nanoparticle is more a surface than a volume. Therefore, as an object gets smaller, the weight of the surface properties starts to become more and more important and the role of the atoms inside is less relevant.

However, it is not just about the importance of surfaces, but rather, moreover, as the size of objects becomes smaller and smaller, other phenomena appear which only the intriguing Quantum Mechanics can explain. Quantum Mechanics must be understood as the "manual of laws and rules" which scientists have writtenin order to understand nature, rules and laws which explainhow molecules and other more and more complex objects are formed, and how these objects react whenfacing mechanical deformations, electric fields, magnetic fields or light. But there is no need for alarm since the participants of the Investiga R&D&I Program are not going to have to study the fundamentals of this exciting discipline (only those who study physics, chemistry, or electronicor telecommunications engineering later on will be able to deepen their knowledge of it). For now, they must know that a series of "quantum" effects appear in nano-objects which provide them with interesting properties. For example, the quantum effects cause that the electrons moving around inside a nanoparticle can only have certain energies, which we call permitted energy levels. Furthermore, as the nano-object becomes smaller, the permitted values for these energies change. As a consequence, many electric, magnetic or optical properties which depend on these energy levelsare also modifiedas the size of the object changes. For example, the nanoparticles of certain semiconductor materials change color as their diameter grows, running through nearly the entire range of colors of the rainbow.

The effects which have been previously mentioned are called "size effects" and they are rather disturbing, since for each size and shape a nano-object has, it shows different properties. This, which seems like

mayhem, is in reality the great strength of nanotechnology: if you control the size and shape of a nano-object, you can control its propertiesand we will thus be in a position to take better advantage of them. The idea is fascinating. Therefore, the final aim of nanotechnologyis to control, by means of physical and chemical methodologies, the shape, size and internal order of nano-objects and nanostructures in order to freely modify their properties. For example, controlling the size and shape of nano-objects, you can modify their electrical conductivity, their color, their chemical reactivity, their elasticity, etc. It is said that we can manufacture "made-to-measure materials" or that we can "calibrate" (or "tune",in young people's slang) the properties of materials at will. This control of matter at a nanometric scale is continually improving thanks to powerful physical tools and new chemical reactions, which make it possible to manufacture nanodevices and synthesize nanomaterials. Moreover, sophisticated instruments allow us to observe what is happening in the nanoworld. Among these instruments we can highlight the new transmission electron microscopes, the scanning tunneling microscope (STM), the atomic force microscope (AFM) or the powerful latest-generation electron microscopes. These tools allow for observation and in some cases even the direct manipulation of atoms and molecules. For nearly 25 years now, human beings have already known how to manipulate atoms, one by one, to make small artificial structures. Nanotechnology has grown up before our very eyes and it can be said that it will soon reach adulthood!

The ideas and tools which are used in nanotechnology are evolving non-stop thanks to the contributions made by biologists, chemists, physicists, engineers, mathematicians and doctors. Nanotechnology is an absolutely multidisciplinary field, open on many fronts. This is so because the components of matter, atoms and molecules, are the same for all of these scientific specialities. On the nanoscale, we all use the same fundamental "bricks": atoms and molecules. Said fusion of disciplines is

called “technological convergence”. Nanotechnology is a great process of convergence which is currently still being forged. Furthermore, it should not be forgotten that biology plays a key role within nanotechnology, since life is in itself pure nanotechnology. All you have to do is observe the inside of a cell to realize that it carries out all of its functions thanks to “nanometric machines”, which operate perfectly thanks to the very long evolutionary process. Moreover, biology presents to us before our very eyes a great arsenal of solutions and strategies which allow us to solve specific problems. Biology is an endless source of “bioinspiration” which can deliver solutions to problems which appear in other areas such as the science of materials or chemistry.

To finish this long introduction, it must not be forgotten to mention that the “nanoproducts” conceived from nanotechnology are gradually invading the economic sectors in their entirety: materials, electronics, information technologies and communications, energy and environment, transport, construction, the textile sector, biotechnology, health, agriculture, food, etc. It is said that nanotechnology is “transversal and ubiquitous”. Nanotechnology is now starting to be a big business and it can be asserted that the future will in part be “nano”.In this new context, it is very important to bear in mind the possible side effects (generally negative) which the advances in nanotechnology might have. These possible negative impacts are not exclusive to nanotechnology; every technology has its friendly face and its dark side: nuclear energy, thermal power plants, vehicles, airplanes, etc. In the case of nanotechnology, it is known that certain nanomaterials are potentially dangerous to health and the environment. It is very important for the use of nanotechnologies to be as harmless as possible for everyone, so studies are being carried out to achieve that they aren’t perceived to be a threat to society, thus slowing down expectations about their development. It is very important to be informed about the pros and cons of each technology so that, as educated, critical citizens, we can

know the implications of all sorts which nanoproducts might have, and thus demand for there to be adequate rules and regulations to guarantee manufacturing, commercialization, consumption and recycling safe both for people and the environment.

Energy and the Environment: two great challenges for humankind.

Since the Neolithic Period, mankind has developed technologies that are applied to the manufacture of materials and products which allow us to have better food, better health, greater transport capacity, cities with more services, etc. However, many of these technologies began when human beings were able to master fire, the first source of energy managed voluntarily by men. In reality, we can't speak about energy sources because energy transforms from one form to another. If we sit down and think about it, in reality the access to energy is the base of practically everything. Without access to energy we couldn't survive, or have the society which we have shaped up. Originally energy was managed by transforming chemical energy stored in firewood intothermal energy which enables heating things or evaporating water. Certain natural fats or oils and mineral oils were also used, later the energy stored in the subsoil in the form of coal or oil began to be used, the potential energy stored in the water in reservoirs also started to be taken advantage of, and the 20th century saw the emergence of atomic energy. In the late 20th century and early 21st century, other energy sources called renewable have started to be usedwhich minimize the environmental impact (massive emission of CO2 and other gases) that the combustion processes of firewood, coal andoil derivatives have. If we reflect upon it a little, we will realize that wood as well as coal and oil are none other than deposits of solar energy from the past, which plants and microorganisms were able to turn into chemical energy. The sun also evaporates water which then fills reservoirs, also heats up the air which enables creating the wind that we take advantage of inwind

turbines, or is indispensable for the growth of plants from which biofuels are obtained. The sun plays a fundamental role in the development of humanity.

I have already commented that the massive combustion of coal and oil derivatives has been key to the development of our societies since the 18th century but has caused problemssuch as the increase in levels of CO2, clearly linked to the increase in temperatures all over the planet, the increase in extreme meteorological phenomena, and the undeniable climate change. The well-being generated by the access to energy sources has enabled the exponential increase in population in these last 150 years, increasing the need to produce food, thetransformation of forests intoarable lands, the construction of more and more human settlements, roads which connect them, infrastructuresto transport energy or signals for us to communicate with one another… Human beings' impact on the environment is more than evident. Moreover, it must be taken into account that up until half a century ago only a few countries and a relatively small fraction of humankind (some 20%-25%) could be considered technologically-advanced societies, and consumers of natural resources, but a great many countries that didn't have the level of development of the United States, Canada, Japan, Germany, France, the United Kingdom, etc. have followed a path of development similar to that of the "rich" countries, accelerating the use of conventional energy sources and the impact on the environment.

In the early '80s a deep reflection needed to be made about the development model based on unlimited consumption and the extreme exploitation of natural resources, where it was taking us towards, and if there were any alternatives. In 1987, this reflection gave rise to a report which was elaborated by a commission of expertsof different nationalities for the U.N.Said commission was led by Norwegian doctor

G.H. Brundtland. The report was originally called "OurCommonFuture". This report, however, has come to be known more colloquially as the "Brundtland Report" and in its pages the term "Sustainable Development" was used for the first time, defined asthat which satisfies the needs of the present without compromising the needs of future generations. The Brundtland Report analyzes the development policies belonging to the globalized economy,which provide broad social progress but have a very high environmental impact. The report proposes a model of sustainable development based on a series of premises: (i) The conservation of our planet, not endangering the ecosystems, flora and fauna which are found on it; (ii) Appropriate development which does not substantially affect the ecosystems; (iii) Relinquishing excessive levels of consumption which are not at the reach of every individual; (iv) Achieving economic growth in poor countries; (v) Establishing demographic control, referring mainly to birth rates; (vi) Using non-renewable resources as efficiently as possible; (vii) Peace, equality and respect towards human rights; and (viii) Democracy.

In 1992, the Conference on Environment and Development took place in Rio de Janeiro. At said conference, the "Rio Declaration on Environment and Development" was proclaimed,which deepened in and clarified the concept of sustainable development. During the '90s, the proposals matured which would have to promote all the ideas there are behind the concept of Sustainable Development. In the year 2000, the U.N. adopted the Millennium Development Goals (MDGs), which was the initiative set forth to uphold the principles of human dignity, equality and equity, and of freeing the world from extreme poverty, which are part of Sustainable Development. In the year 2015, it was demonstrated that not all of the goals proposed in the MDGs had been achieved. In view of this non-compliance, the U.N.did not relent in its determination and in September 2015, representatives from 193 countries adopted a historic commitment upon approving the 17 Sustainable Development

Goals(SDGs) which wereagreed upon following over 3 years of negotiations between representatives of all the U.N. member countries, non-governmental organizations and other social agents.Along general lines, the SDGs aim, just like the MDGs, to end poverty, combat inequalityand fight against climate change for the next 15 years, with the purpose of achieving adignified life for all without anyone being left behind. The new strategymust be developed between 2016 and 2030.The list of the SDGs is long, but we are only going to select the ones related to the topic energy+environment:

- Goal 6. Ensure availability and sustainable management of water and sanitation for all.
- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all.
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation to support economic development and human well-being, with a focus on affordable and equitable access for all.
- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.
- Goal 13. Take urgent action to combat climate changethrough education andawareness-raising of people as well as the negotiation of national and international agreements and measuresfor all to act together against climate change; minimizing its impact on people's lives.
- Goal 14. Conserve and sustainably use the oceans and seas.

It is clear that the goals are very ambitious and that every government and organization, together with every inhabitant on the planet, are expected toget involved (for us to get involved) in achieving them. The subject of climate change and sustainability is not only an issue for governments; it is a subject that involves society from its foundation.

Institutions like the U.N. and the Catholic Church or entities such as Green Peace call our attention to these subjects and the need to take specific measures. Particularly interesting is theEncyclical LetterLaudatoSI' by Pope Francis I about "The Care of Our Common Home", where he bravely tackles issues like pollution, climate change, waste recycling, etc.

It seems evident that the proposed subject this year, energy and the environment, is key for the future of humanity, which requires great awareness of everyone and implies putting into practice specific policieswhich enable the development and use of new technologies which allow re-balancing the damage caused by our species on the planet, at the same time as our survival is assured on it in a dignified way. And what role can nanotechnology play in all of this? That is precisely what the participant in this program has to find out, although in the following section we provide some clues.

Subjects to reflect upon, debate and develop in the papers.

At this point we already know the two work topics; on the one hand nanotechnology, and on the other energetic and environmental challenges. Now we need to connect them. We have seen that nanotechnology, transversal and multidisciplinary in nature, provides solutions in practically every economic sector: health, energy, automobile, space, food, cosmetics, security, agriculture, etc. Nanotechnology can be made out as the driving force of a new revolution. It will be enhanced even further when it converges with biotechnology, information and communications technologies (ICTs), and the breakthroughs in neuroscience. However, nanotechnology doesn't have a direct application but rather through the materials and devices which are going to be used, at the same time, for sectors like electronics, communications, construction, energy, etc. As it was said

earlier, nanotechnology is a transversal technology that is applied in many sectors and that will be "hidden" in many materials and devices, which will have surprising applications.

It is evident that the field of applications of what is "nano" is very extensive and certain applications need to be focused on or certain nanomaterials which are the main characters of nanotechnology. In view of what was stated in the previous section, it is obvious that nanotechnology has a lot to say in subjects related to the management of energy and the environment. The papers which the participants must develop in this edition of the Investiga R&D&I Programmust be based on research andconsultations of research articles, press articles, hundreds of web pages, blogs, etc. and other types of documents which deal with how nanotechnology can contribute to improving ouruse of energy resources at the same time as we slow down the deterioration of the planet. The papers must deal with aspects that make it possible to respond to some of the questions (not to all of them, which isimpossible in a single paper) which are raised on this list:

- What types of nanomaterials or nanodevices are going to be used in the substitution of fossil fuelsto make way for the extensive use of renewable energies?
- What examples of application are there now regarding prototypes and even commercial use?
- How can nanotechnologies be used to guarantee access to drinking water in those places where it is now difficult to find?
- How will nanotechnology be usedfor the purification of pollutants both in water and in the atmosphere?
- Will nanotechnology enable construction of buildings which require less energy consumptionboth in the construction phase and during its period of use?
- How will nanotechnology affect the development of transports which are more ecological and less polluting?

- Will current production systems (based on the use of scarce raw materials, large amounts of energy, and emitters of pollutants) be able to be replaced byothers less aggressive to the environment, with the help of nanotechnology?
- Is the mass production and use of nanomaterials (such as nanoparticles, carbon or graphene nanotubes) going to be the cause of environmental problems whichaggravate the current situation? How can we avoid them?

The participant will surely find plenty of information about materials or devices which provide an answer to some of these questions. Some examples of specific topics which might appear in the searches and which can be developed in the paper are:

- the use of magnetic nanoparticles for water purification
- membranes based on graphene, porous nanostructured materials for water purification or desalination
- quantum dots to be used in new generations of solar panels
- nanomaterials like graphene to improve the efficiency of organic solar cells
- LEDs / OLEDs as a ubiquitous lighting system
- graphene as a material to be used in different parts of batteries or supercapacitors of lithium as well as sodium
- nanostructured materials which enable making superconductor cables for savings in the transport of electricity
- systems based on nanoelectronics capable of carrying out efficient artificial photosynthesis
- more efficient catalysts to reduce harmful gas emissions from our vehicles
- lighter and tougher nanocomposite materials to be used in theblades of wind turbines, airplane airframes or vehicles
- nanomaterials to be used in hydrogen fuel cells

- nanofluids or graphene for the improvement of thermal conductivity
- nanomaterials which improve the thermal insulation of textile products and homes

As you can see, the topics for the papers which can be done are very extensive and it corresponds to the participant in the program to detect an intersecting subject, delve into it and its different aspects, in order to elaborate a report which reflectshis or her main findings and principal conclusions reached. Obviously, besides the previous aspects, the participants will raise new questions and new responses, which will provide their papers with a great added value and originality.

General advice

To make life easier for the expert who will supervise the work, it is recommended to bear in mind the following guidelines:

- Carry out the paper trying to focus on the proposed subject, avoiding elaborating on other themes such as the applications of nanotechnology in medicine, sports, food, etc.
- The paper must be specific, not very long, avoiding too lengthy introductions to nanotechnology. A maximum of 25 pages is recommended.
- Structure the paper in well-differentiated sections and sub-sections, which respond to argumentative logic.
- Write clearly, without spelling mistakes and with good syntax.
- Avoid plagiarizing other works or websites. "Cutting and pasting" is not allowed. Phrases quoted literally must be in quotation marks and their source must be conveniently cited.
- Make a good selection (it needn't be very long) of references. Try to minimize references to news published in the media, and go to

original sources (research groups, universities, etc.). In the reference, indicate the title, author, date and web links.

- Include photos or pictures (citing their source) only if they are related to the written text. Do not simply include illustrations, or include an entire set of pictures at the end. You have to attempt to insert each image or photo in the place where it corresponds with its caption.
- If it is possible, it is recommendable to include some activity or experience or your own: surveys and their analysis, an interview with researchers, a report on a laboratory visit, an experiment carried out in the classroom, etc.
- It is also very important to include reflections and (reasoned) opinions of your own in the paper.
- In the document, the title of the paper, the topic, the authorship and the school or institute of origin must be clear.

References and support materials

Before listing some references of possible use, it must be mentioned that an Internet browser can find tens of millions of sites related to nanotechnology. In this as in other subjects, there is a surplus of information and, therefore, you must be cautious when choosing the most suitable sources of information, this phase being of great importance to correctly carry out the research work. The references which are shown are related to nanotechnologyin general and some have been added related to the subject proposed in this edition. The search for accurate, useful references about the proposed themes is part of the work which each participating student must develop. These references, together with the ones which are shared in the forum, are just the starting point of a long road which will last several months. Good luck!

Links related to the subject "Nanotechnology"

- Guides prepared in previous editions of the Investiga R&D&I Program for the subject of Nanotechnology, together with some of the presentations carried out by the student finalists, can be downloaded at:
    - http://www.fundacionsanpatricio.com/investiga/pdf/Guiananociencia.pdf
    - http://www.fundacionsanpatricio.com/investiga/pdf/guias2011/GUIANANOTECNOLOGIAPARALAALIMENTACIONYELCONSUMO.pdf
    - http://www.fundacionsanpatricio.com/investiga/pdf/guias2012/GUIA_NANO-ROBOTS.pdf
    - http://www.fundacionsanpatricio.com/investiga/pdf/nuevosmaterialesparaeldeporte.ppt,http://www.fundacionsanpatricio.com/investiga/pdf/PresentacionNanotecnologia.ppt,
    - http://www.fundacionsanpatricio.com/investiga/pdf/LINEA%204%20-%20NANO.ppt
    - http://www.fundacionsanpatricio.com/investiga/pdf/guias2014-15/GUIA4_INTRODUCCION_NANOTECNOLOGIA-NANO_QUE_LLEVAMOS.pdf
- "Unidad Didáctica de Nanociencia y Nanotecnología" ("Didactic Unit on Nanoscience and Nanotechnology") (J.A. Martín-Gago, E. Casero, C. Briones and P.A. Serena, FECYT, 2008). Available free in the digital version on the websitehttp://www.fecyt.es or at the addresshttp://www.oei.es/salactsi/udnano.pdf
- P.A. Serena's presentation on nanotechnology (PowerPoint). Available athttp://www.fundacionsanpatricio.com/investiga/pdf/presentaciones2013-14/PresentacionNanotecnologia-AutorExpertoPedroSerena.ppt
- P.A. Serena's presentation on nanotechnology (PDF). Available athttp://www.fundacionsanpatricio.com/investiga/pdf/presentaciones14_15/PresentacionNanotecnologiametodologiasymaterialesparaelaula.PedroSerena.pdf

- "La Nanotecnología" ("Nanotechnology") (P. A. Serena, "What do we know about…" Collection, Editorial La Catarata and the CSIC, Madrid, 2010).
- "El nanomundo en tus manos" ("The Nanoworld in Your Hands") (J.A. Martín Gago, C. Briones, E. Casero and Pedro A. Serena, Colección Drakontos, Editoral Crítica, 2014).
- "Los Riesgos de la Nanotecnología" ("The Risks of Nanotechnology") (M. Bermejo and P. A. Serena, "What do we know about…" Collection, Editorial La Catarata and the CSIC, Madrid, 2017).
- TV series "Qué sabemos de la nanotecnología" ("What Do We Know about Nanotechnology?"). The National Distance Education University (UNED) and the CSIC. This series consists of 17 episodes which can be accessedthrough the linkhttps://canal.uned.es/serial/index/id/875
- On the website http://product.statnano.com/ there is an inventory of Nanotechnology products in which over 8000 products are already mentioned which contain some type of nanocomponent.
- Another inventory of products (over 3000) athttp://nanodb.dk/
- The beauty of the nanoworld can be observed in the picture gallery of thefinalists of the international contest SMPAGE, co-organized by the CSIC and the Universidad Autónoma de Madrid (http://www.icmm.csic.es/spmage). These galleries are of free use.
- The daily newspaper "El Mundo" has a complete section devoted to nanotechnology full of news, articles and interviews. http://www.elmundo.es/elmundo/nanotecnologia.html
- In Spain, a great many research groups that work on the subject of nanotechnology are grouped in the Red Española de Nanotecnología (NANOSPAIN) (http://www.nanospain.org).In the "Members" section, over 370 groups that work on this subject can be identified, which can be of interest in order to carry out interviews that can be included as part of the paper.

- National Nanotechnology Initiative of the United States. (NNI, http://www.nano.gov/). There is an interesting section devoted to educational topics with a lot of resources.

Links related to the subject "Energy and Environment".

- Brundtland Report. "Report of the World Commission on Environment and Development: Our Common Future", United Nations Organization, 1987. Available at: http://www.un-documents.net/our-common-future.pdf
- U.N. Sustainable Development Goals (2016–2030). Link:http://www.un.org/es/millenniumgoals/beyond2015-news.shtml
- U.N. "Outcome document project of the United Nations summit for the adoption of the post-2015 development agenda". http://www.cepal.org/sites/default/files/events/files/2030_agenda_es.pdf
- Nanotechnology in the Horizon 2020 Program of the European Union (http://ec.europa.eu/research/industrial_technologies/nanoscience-and-technologies_en.html).
- "WTEC Panel Report on Nanotechnology Research Directions for Societal Needs in 2020 Retrospective and Outlook", September 30, 2010, Editors Mihail C. Roco, Chad A. Mirkin, Mark C. Hersam, WTEC,NSF, United States. (http://www.nano.gov/sites/default/files/pub_resource/wtec_nano2_report.pdf). The impact of nanotechnology is pointed out topic by topic in this report. It can be a good guide for the teacher to steer the students with.
- European Nanotechnology landscape report, ObservatoryNANO, 2010 (http://www.nanotec.it/public/wp-content/uploads/2014/04/ObservatoryNano_European_Nanotechnology_Landscape_Report.pdf). In this report, there are many

applications of the "nano" subject in energy and the environment. It can be a good guide for the teacher to steer the students with.

- "Un planeta en busca de energía" ("A Planet in Search of Energy") (Pedro Gómez Romero, Editorial Síntesis, 2007).
- http://www.cienciateca.com/ (Website with quite a few dissemination articles about the subject of energy and nanotechnology).
- "Nanotecnología y Energía" ("Nanotechnology and Energy") (NationalNanotechnologyInitiative –NNI, 2014, brochure in Spanish aimed at young people)https://www.nano.gov/sites/default/files/pub_resource/nano_energy_brochure_spanish_for_web_jan_28_2014.pdf