The following case-studies of nanomaterial collaboration projects between the EU and Eastern Partnership Countries were supported via the EU-funded FP7 NANOMAT-EPC project.

The two year collaboration pilot projects involved short term exchanges and training in scientific techniques.

Pilot Project with Armenia

In recent years, the Institute for Physical Research of the National Academy of Sciences of Armenia (IPR-NAS) has developed a method of solid-phase pyrolysis of phthalocyanines. This has enabled IPR-NAS to synthesise ferromagnetic (Ni, Co, Fe) and superparamagnetic nanoparticles in different carbon matrices, which have potential use for self-regulating magnetic hyperthermia in oncology and as contrast-agents in magnetic resonance imaging.

Magnetic hyperthermia works on the principle that magnetic nanoparticles produce heat when subjected to an alternating magnetic field of specific amplitude and frequency. By positioning the nanoparticles close to a tumour and then subjecting them to a localised alternating magnetic field, the tumour can be heated up and destroyed.

To facilitate the transfer of the technology and associated knowledge to the healthcare sector, IPR-NAS needed the support of Laser Zentrum Hannover (LZH) to educate and train them in:

i) how to measure the structural and magnetic characteristics of ferromagnetic and superparamagnetic (Ni – Cu)/C nanocomposites with Curie temperatures in the range of 42-47 degrees centigrade and
ii) how to test the best samples in self- regulating magnetic hyperthermia

Dr. Laszlo Sajti (LZH) and Dr. Aram Manukyan (IPR-NAS)

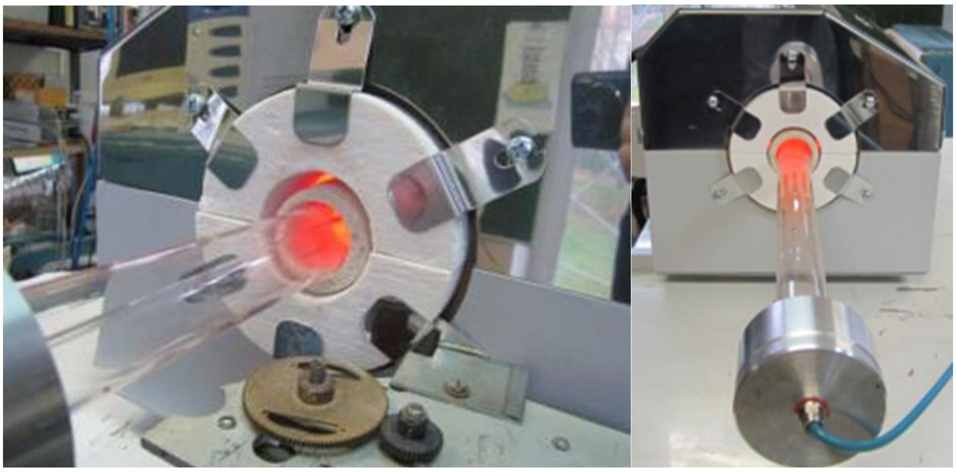
During the two year project, the scientists were able to test and improve the magnetic nanoparticles produced by IPR-NAS. Most notably, they managed to create laser-generated iron nanoparticles exhibiting significantly faster/better response to radio-frequency inductive heating in comparison to commercially available super-paramagnetic iron oxides (Fe_3O_4 from Endorem® with magnetisation 93 emu/g). This was thanks to the special structure of the nanoparticles (iron core/oxide shell with magnetisation 218 emu/g), which combined high magnetic properties with outstanding electrical conductivity.

The scientists' results were recently published in the international journal Nano (10, 1550089, 2015).

Thanks to the scientists' collaborative efforts, the new nanoparticles have been brought a step closer for use by oncologists as a non-invasive cellular treatment as well as a new MRI contrast agent.

Pilot Project with Belarus

The Belarusian State University of Informatics and Radioelectronics (BSUIR) has developed a chemical vapour deposition method for producing high quality ordered hybrid carbon nanotube (CNT) / graphene nanostructures where the graphene layers are allocated on the top of the arrays of vertically allied CNTs. BSUIR's production process for these nanostructures takes several minutes instead of weeks. Their simple, low-cost, one-step process uses a volatile catalyst and is fully compatible with microelectronics production technology.



BSUIR's chemical vapour reactor during synthesis

Based on these unique nanostructures, BSUIR's CNT/graphene nanostacks demonstrate good electron conductivity, low diffusion resistance to protons/cations, easy electrolyte penetration, and high electroactive areas. Consequently, they represent promising candidates for the fabrication of high performance supercapacitors with superior specific electrical capacitance.

In order to bring the technology a step closer towards application in the clean energy sector, BSUIR needed the support of Cleancarb - a Luxembourg-based company specialised in energy storage systems for electric vehicles - to educate and train them in:

i) how best to integrate the electrodes into supercapacitor cells and
ii) how to perform and analyse comparative vehicle based tests using commercial supercapacitors with BSUIR's hybrid CNT/graphene electrodes.

This would enable BSUIR to have a deeper understanding of the behaviour of the electrodes under typical operating conditions and prove their high performance, reliability and durability.

During his short term secondments to Cleancarb, Dmitry Grapov, a young BSUIR researcher, also visited several research centres in Luxembourg, as well as the company 4ESYS specialised in supercapacitor applications for automotive and industrial clients. This helped him to gain useful industrial insight that he was able to then utilise in producing the CNT electrodes. Meanwhile, during visits to Minsk, Peter Dooley, Cleancarb Managing Director, was trained in material synthesis for CNT electrodes and advised BSUIR on how to conduct supercapacitor electrical performance tests.

Over the course of the two year-project, the partners produced more than fifty electrodes made of ordered hybrid CNT/graphene nanostructures, and more than forty-five electrodes made of ordered hybrid CNT/graphene nanostructures. Samples of these electrodes were integrated into supercapacitors in order to make comparative performance tests with “off-the-shelf” industrial supercapacitors.

Although the results for specific electrical capacitance (0,6 F/g) proved slightly disappointing, the partners see potential to make major improvements by using laser patterning to improve the electrolyte access to deep layers of the CNT/graphene material, and direct metallic electrical connection to the CNT/graphene film.

Furthermore, the project has enabled the partners to identify a new application for BSUIR’s CNT/graphene material in the field of microelectronics. This requires further investigation thus creating room for future collaboration between BSUIR and Cleancarb.

Pilot Project with Georgia

Rare-earth metal compounds represent very promising materials to use in sensor elements for various types of photonics devices: communications, light and light sensor devices, imaging for safety & security, and optical sensors for high average and high peak power lasers. During the past 25+ years, the Georgian Technical University (GTU) has conducted research on light radiation sensors based on rare-earth metals and their compounds. Their research has principally focused on:

- Heterogeneous combination of elements to integrate higher levels of intelligence into multifunctional microsystems including multi-sensing, processing, wireless and wired communication, and/or actuation capabilities;
- Smart systems based on innovative nanosensor devices and components, providing unprecedented levels of performance and representing a disruptive approach to known or new challenges;
- Integration of multiple elements of the value chain of heterogeneous systems - materials, modelling, design, processes, devices, packaging, characterisation, testing - contributing to more efficient manufacturing.

In order to introduce GTU’s technology to the environmental monitoring sector, GTU needed Université Paris-Sud (PSUD) to educate and train them in:

i) nanomaterial preparation and measurement using picosecond laser technology for preparation of very thin nanofilms, and precise optical and magnetic properties measurement methods at liquid helium temperatures and

ii) testing methods for radiation nanosensors in hospitals, chemical and metallurgical factories for monitoring of different chemical, biological and other harmful substances.

Prof. Paata Kervalishvili and Dr. Tamara Bzhalava (GTU)
with Dr. Christophe Humbert (PSUD)

GTU paid several visits to PSUD's Laboratory of Chemical Physics, where they received training for the lab's state-of-the-art facilities: ELYSE, used for investigating fast kinetics, and CLIO, a free-electron laser. In particular, they learnt how to perform sum frequency generation spectroscopy. During the visits, the GTU researchers performed over fifty experiments with the PSUD experts.

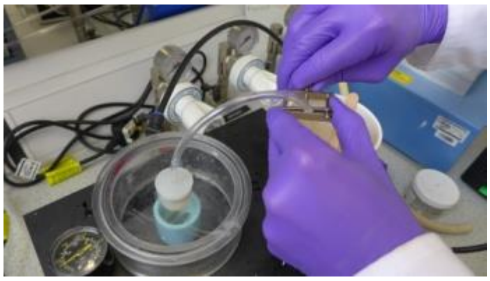
By exploiting PSUD's advanced technical facilities and the combined knowledge of the Georgian and French experts, the partners discovered that significantly enhanced results could be obtained by producing boron 10 samples on aluminium substrates compared to silicon substrates. The partners aim to test the improved samples on different biological tissues in the near future.

Furthermore, the research results obtained during the course of the project were published in a number of international journals, including the *American Journal of Condensed Matter Physics*, as well as several conferences, including the *International Conference on Diamond and Carbon Material*.

Pilot Project with Ukraine

In recent years much development has focused on solid oxide fuel cells (SOFC) as a source of clean electric power, because they are able to convert a wide variety of fuels and because they do so with such high efficiency (40-60% unassisted, up to 70% in pressurized hybrid system) compared to engines and modern thermal power plants (30-40% efficient). SOFC technology dominates competing fuel cell technologies because of the ability of SOFCs to use currently available fossil fuels, thus reducing operating costs. Also, SOFCs are attractive as energy sources because they are clean, reliable, and almost entirely non-polluting. Because there are no moving parts and the cells are therefore vibration-free, the noise pollution associated with power generation is also eliminated.

During the past 5+ years, Frantsevich Institute for Problems of Materials Science of the National Academy of Sciences of Ukraine (IPMS) has been conducting research to radically improve the ionic conductivity in zirconia electrolytes and the mechanical properties of SOFC. In particular, their work has focused on nano-sized SOFC materials sourced from Europe's solitary zircon-sand deposit which is located in Ukraine. Their research has indicated an improvement by a factor of five in the ionic conductivity of zirconia may be achieved by combined use of Ukrainian 10-mol.% Sc2O3 – 1-mol.% CeO2 – stabilized zirconia powder, and electron beam physical vapour deposition technique for the dense electrolyte and diffusion barrier layers to be deposited on porous Ni-ZrO2 anode.



SOFC cell development and testing

In order to bring the technology a step closer towards application in the clean energy sector, IPMS needed the support of the University of Birmingham (UB) to educate and train them in:

i) characterization of zirconia powders using Hg porosimeter and IS Impedance Analyser and
ii) long term performance tests to evaluate the SOFC with zirconia anodes.

This would enable IPMS to have a deeper understanding of the behaviour of the new SOFC electrolyte materials under typical operating conditions in order to prove their high performance, reliability and durability.

During his visits to UB, Dr. Yehor Brodnikovskyi, a young IPMS researcher, was trained on a variety of instruments used to manufacture, analyse and characterise SOFC utilising IPMS' zirconia anodes. Similarly, Nikkia McDonald, a young UB researcher, spent time in Kyiv learning more about IPMS' zirconia anodes. The IPMS and UB researchers obtained their best power density results by combining a NiO-10Sc1CeSZ anode with 10Sc1CeSZ electrolyte, gadolinia-doped ceria barrier layer, and LSCFGDC cathode in a single chamber SOFC.

Their results were expected to be published in late 2015 in an international, peer-reviewed journal. Meanwhile, looking to the future, the partners hope to continue their collaboration on the anode technology via the EU's Fuel Cells and Hydrogen Joint Undertaking, which Ukrainian organisations are now eligible to participate in since 2015.