Impact Objectives

- To continue the development of groundbreaking research projects which have helped form the building blocks of the technologies of day-to-day life
- Reduce the cost of EET, thus allowing more people to benefit from the superior treatment of wastewater
- Further develop the collaborative nature of their work by communicating and developing links with materials researchers around the world in a bid to facilitate future breakthroughs

Nature at our service

By focusing on developing biological self-sufficient anodic cells, ***Dr Akihiro Okamoto*** *and* ***Professor Shuji Nakanishi*** *are on the way to implementing novel strategies in residues treatment. Here we discuss this possibility further*

(From top left, clockwise) Dr Okamoto, Professor Nakanishi, Dr Nakamura and President Hashimoto

What was the most challenging aspect of your research, and how did you overcome the obstacles?

Hashimoto: Microbes with the capability of extracellular electron transport (EET) were discovered more than 25 years ago, but the most intriguing aspect of this molecular mechanism remained largely unexplored. As a process that occurs in live entities, EET takes place in non-equilibrium conditions and relies on a complex net of transport proteins, which has never been understood under the light of Marcus' electron transfer theory. The discovery of flavin-binding proteins, fulerum to activate the outer-membrane electron transport enzyme, represented a victory to our group, as it resulted in the discovery of respiration with fermentative energy conservation during EET process. Such an advance in understanding EET was only possible due to the precise electrochemical techniques and physical chemistry background we applied in this step.

How does this discovery translate to different industries?

Okamoto: Upon this discovery we focused on developing highly sensitive electrochemical techniques to monitor, control and optimise biological electron flow. The novel techniques and knowledge we applied expanded the view for microbial anaerobic respiration associated with EET, and were key to unveiling the dynamics of electron and cation transport process in intact microbial cells.

EET associated with substrate-level ATP synthesis, which is hybrid to respiratory electron transport chains and fermentative energy conservation, has a great potential to open up new ways of exploring technologies for metabolic engineering, and drastically enhance the rate of fermentation reactions by controlling the rate in which EET occurs. Since we already identified the main enzymatic complex for EET orchestration, we may be able to genetically manipulate microbial species useful in fermentation reactions, by inserting the gene for the complex. Or, we can modify Shewanella oneidensis, our primary EET study model, into an organism capable of performing fermentation.

Nakanishi: Furthermore, redox polymers are capable of transporting electrons between electrodes and intracellular electron transport chain, allowing us to deactivate anaerobic iron corrosion induced by EET microbes by simple electrochemical poising. The process is relatively simple, as we applied an electrical potential to the iron portion through a 3-electrode electrochemical system to achieve a protective effect on the metal's surface. This proved effective in reducing metals corrosion when exposed to EET microbiota.

EET microbes seem a potential source of energy. How do you think your research will impact the energy and resources' field?

Nakamura: EET cells aren't considered main energy sources by themselves, but we can aim to build self-sufficient metallic/biologic systems by solely using microbial fuel cells, in locations far from electricity sources. Think about deep sea stations, or even spaceships in a distant future. As for our main focus – the treatment of wastewaters – a self-energised wastewater plant may be possible in the future, we hope. Wastewaters would be treated in anode chambers and simultaneously generate electricity associated with cathodic oxygen reduction.

Okamoto: For small-scale applications, the main impact will be in terms of logistics. For example, in corrosion models, its inhibition will save a lot of energy and associated costs. In industrial metabolic reactions, because fermentation is slow and its rate limits the benefit of bioprocesses, the rate enhancement for fermentation reaction is beneficial. The addition of riboflavin, which specifically enhances the EET rate, can be easily implemented in these industries, at a very low cost. Overall, our findings indicate there are more intriguing fundamental subjects of science that EET research can explore.

Forging the Future

*Hailing from the **National Institute of Material Science (NIMS)**, which celebrates 15 years since its foundation, Dr Akihiro Okamoto leads a promising study on extracellular electron transport (EET)*

Technology today has progressed considerably in ways previously considered unimaginable, and is present in most mundane aspects of society. From transportation services to infrastructure, the building blocks of day-to-day technologies stem from a range of materials that are seemingly common. But this degree of development wouldn't be possible without the efforts of many researchers worldwide. For 15 years, the National Institute of Materials Science (NIMS) in Japan has stood out as an authority in the field, contributing many groundbreaking research projects that have proved indispensable to the future.

POWERING UP

Among on-going research projects, the manipulation of extracellular electron transport (EET) stands out as a revolutionising tool for the bioengineering field. Dr Akihiro Okamoto, senior researcher at NIMS, along with Professor Kazuhito Hashimoto (President of NIMS), Professor Shuji Nakanishi from Osaka University, and Dr Ryuhei Nakamura from the institute of RIKEN (all four were formerly from the laboratory of Professor Hashimoto at the University of Tokyo) are leading a project that seeks to better understand what was a mysterious mechanism for decades, and how it impacts the environment.

The researchers are focused on monitoring, controlling, and optimising biological electron flow in microbial cells, using pioneering electrochemical techniques. By coupling electric perturbation with the delivery of heterocyclic compounds to colonies of Shewanella oneidensis, the team has succeeded in increasing electron flow and ATP formation for those microbes. Despite the study being in its infancy, it is the first to quantify electron kinetics and presents a novel approach to anaerobic respiration models. 'EET is a common phenomenon in nature to sustain the ecosystems' explains Nakamura, 'and controllable to use in various applications.'

Nakanishi's team aims to implement their techniques in treating wastewaters and generate electricity through EET's cathodic oxygen reduction, however the team is confident that EET manipulation can be adapted and applied to a variety of scientific fields. 'The technology we're using is nearing its full practical effect, but we need to further decrease the cost, compared to the current sludge technique.' Mastering this process also unlocks the possibility of enhancing fermentation-bound processes in industries, environmental diagnosis, controlling cellular biological clocks, and finding novel means to screen noble enzymes by coupling EET-microbes monitoring and electrochemical methods.

Currently, EET studies at NIMS are a key element in an international consortium between Japanese researchers, universities, and international experts. 'The generality and impacts of EET in nature has just begun to be recognised in the society of microbiology and physical chemistry,' Okamoto adds. 'The field of EET studies started in the US, but many Asian and European groups have joined. Therefore, the International Society for Microbial Electrochemistry and Technology (ISMET) is now expanding.'

DEFINING THE FUTURE

Together, Okamoto and Nakanishi expect to work towards the development of self-sustainable technologies, through the use of EET. 'Overall, our findings indicate there are more intriguing fundamental subjects of science that EET research can explore,' Nakanishi adds. The possibility of directing electrode synthesis to produce useful chemicals from CO_2, or induce fermentation are secondary, yet impacting advances in electrochemical research within the EET consortium. 'In our case, we conducted fundamental research toward the development of the practical application,' says Okamoto. 'Even for fundamental researches, first we should set goals that can contribute to modern society and technologies. The big picture we are looking at now is the integration of knowlege of non-equilibrium electron transfer in EET processes with material development.' With this goal in mind, EET is set to pave the way to a better and easier future for those to come.

NIMS' journey towards a better future for humankind began with the merging of the National Research Institute for Metals (NRIM), founded in 1956, in Tokyo; and the National Research Institute for Inorganic materials (NIRIM) in 1966. Based in the city of Tsukuba in Japan, NIMS concentrates most of its research work in four sister locations in Japan – Sengen, Namiki, Sakura, and Nishi-Harima. As of April 2016, it employs 1,489 researchers and administrators, creating bold, new fields of research and industry. Running on a system of the National Research and Development Agency, NIMS is the only Japanese institute specialising in materials science, mostly through fundamental research in both generic and infrastructural techniques in the field of materials science, honing and perfecting scientific materials and associated technologies.

The beauty and effectiveness of the research conducted at NIMS resides in small changes to materials already known to humankind as having a vast impact on societal sustainability. Notably, researchers at NIMS contributed substantially to the reduction of energy consumption with studies on superconductive materials and heat-resistant super-alloys; smart polymers pivotal in high-end medical treatments; as well as long-life structural elements, which are already integrated into Japan's transportation systems.

KEEPING IN TOUCH

Communication and cooperation between scholars, researchers, and experts alike is one of the main goals of NIMS, and crucial for future breakthroughs. 'In addition to the international conference every second year, we attend NA (North America), EU (Europe), and PA (Pacific Asia) conferences, in concert with ISMET too,' Okamoto says. 'Aside from talks or workshops at these conferences, we use press releases, our homepage, and academic social networks (Research Gate, Loop) to spread our findings to the world.'

NIMS' presence among the scientific community is further endorsed through

> *In recent years, it has frequently been necessary to promote research cooperatively, by a fusion of the capabilities of diverse fields, in order to solve a single research problem*

regular publications of in-house journals such as NIMS NOW International, which feature NIMS' latest research activities, international collaborations, as well as the main trends in materials' science.

Alongside these efforts, NIMS has implemented cooperative graduate programs, which have proven essential to expand the foundation's reach, and build an ever-growing net of outstanding collaborations. Through these initiatives, NIMS has succeeded in acting as a training ground for materials science majors, accepting dozens of national and overseas candidates as trainees in different departments, under the supervision of native researchers.

In February 2016, the NIMS administrative board established the first Collaborative Research Centre in Europe, thus cementing the partnership with Grenoble's centre, MINATEC.

In the future, NIMS' focus is mainly on introducing new ways to integrate superconductors, ceramics, and organic materials developed within the institute to a wide range of electronics, optics, catalysts and biotechnology appliances.

With the beginning of its fourth seven-year plan, NIMS will be integrating the changes it implemented on its third Mid-Term Program, to better respond to upcoming challenges in research. 'Research was carried out by a one-to-one system, in which one research centre was responsible for one research project. However, in recent years, it has been necessary to promote research cooperatively, by a fusion of the capabilities of diverse fields, in order to solve a single research problem,' Hashimoto states. By reorganising the existing research system in fields of specialisation, NIMS is keen to tear down the barriers between those fields, and promote cooperative and translational research methods. 'Research on materials has contributed to the prosperity of humankind in many ways,' Hashimoto concludes, 'as most advances have enabled a higher degree of comfort and practicality.' With this goal in mind, NIMS' promise is to pave the way for a better and easier future.

Project Insights

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PROJECT COORDINATOR BIOS

Dr Akihiro Okamoto recently became Senior Researcher at NIMS and was formerly assistant professor at the Department of Applied Chemistry of The University of Tokyo, Japan.

Professor Shuji Nakanishi was formerly associate professor at The University of Tokyo, and is now a professor at the research centre for solar energy chemistry (RCSEC) of Osaka University, Japan.

Dr Ryuhei Nakamura is currently leading the Biofunctional catalyst research team at RIKEN CSRS as a principle investigator.

Professor Kazuhito Hashimoto is currently leading NIMS as president, and is also a professor at The University of Tokyo.