TRANSFORMING RESEARCH INTO SUSTAINABLE SOLUTIONS

Scientists from Nanyang Technological University, Singapore, are working hard to MITIGATE HUMAN IMPACT ON THE ENVIRONMENT.

Earth is on the cusp of a crisis. The United Nations projects the global population will reach roughly 10 billion by 2050, creating a growing demand for food, water, energy, and other essentials. In parallel, the effects of climate change are becoming more manifest, with temperatures increasing by nearly 0.2 degrees per decade, fuelling an urgent need for more sustainable means of production and sound strategies for environmental protection.

Nanyang Technological University, Singapore (NTU Singapore) is at the forefront of efforts to develop scientific innovations that can be directly translated into practical sustainability solutions. According to materials scientist, Nripan Mathews, Singapore, as a tropical, highly urbanized island city-state, is an ideal test-bed for such technologies. “It is a ‘unit-cell’ of future developments that will happen all over the world,” says Mathews. “We are already attacking problems that future megacities would have.”

Researchers at NTU are addressing sustainability from multiple angles, from renewable energy, to environmental remediation, to biodegradable materials. This work benefits not just from robust funding—NTU scientists drew over S$587 million in grants in 2019–20—but also funding from firms like Temasek, which is moving numerous NTU research programs into commercial development.

WE ARE ALREADY ATTACKING PROBLEMS THAT FUTURE MEGACITIES WOULD HAVE

A SMARTER SOLAR STRATEGY

Singapore is pushing hard for broad adoption of solar energy in the coming years. “We have a target of two gigawatts peak solar production installed by the end of 2030,” says Subodh Mhaisalkar, executive director of the Energy Research Institute at NTU, “and we have a 50% reduction target for [greenhouse gas] emissions by 2050.” However, although sunlight is abundant on the island, real estate is not—and great innovation is needed to develop solar panels that can make the most of limited space.

Mhaisalkar, Mathews, and physicist, Tze Chien Sum, are developing two different approaches based on perovskites, a class of materials whose crystal structure makes it well suited for solar energy production because of its highly efficient light absorption properties. One way is to make conventional large-scale ‘tandem’ solar modules that combine perovskite- and silicon-based solar cells. Historically, researchers have struggled to achieve high efficiency in converting light to energy outside tiny laboratory-scale perovskite devices. But in July 2020, Mhaisalkar and colleagues published work describing 21 cm² perovskite solar modules that achieve record-setting conversion efficiencies of over 18%.

Units of this size can be assembled into commercially useful panels. And since the NTU team is employing a commonly used evaporation-based process to manufacture their cells, they are optimistic about the technology’s prospects. “For tandem solar cells, I think there is consensus that we will hit 30% efficiency some time this year,” Mhaisalkar says, which is well above the efficiency of current silicon-based modules. If the team secures a commercial partner, he estimates that their panels could be in production within a year or two.

These cells are not ideal for all environments, so the NTU team is also developing perovskite-coated glass solar panels that could turn every window in Singapore into a generator. These are made through essentially the same screen-printing process used to make T-shirts, which simplifies production greatly, but doesn’t account for other major materials challenges. “What is considered ‘thin’ for normal glass is very, very thick for us in the lab,” says Mathews. The researchers have now spun out a company called Prominence Photovoltaics—supported by a million-dollar Temasek Ecosperity Grant —to further develop their glass production and perovskite-printing technologies in parallel.

Sum notes that NTU is

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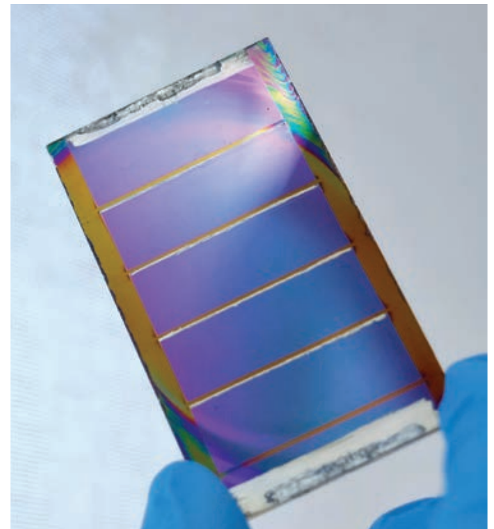
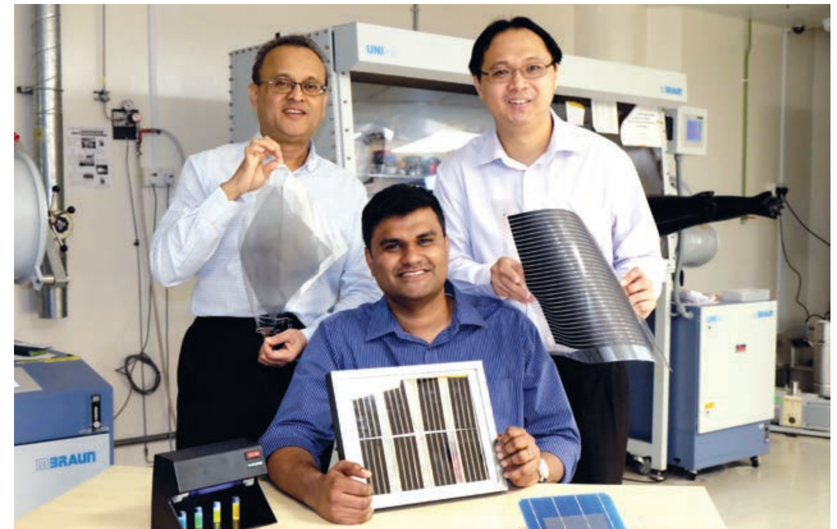


Perovskite solar cells fabricated at NTU Singapore.



(From left) Subodh Mhaisalkar, Nripan Mathews, and Tze Chien Sum.

Biofilms may help researchers to both protect coastal cities and facilitate marine biodiversity.

particularly well-situated for demonstrating the stability of their solar cell designs. “Humidity is one of the biggest enemies of perovskites,” he says. “Singapore has very high humidity, and if we can get perovskite solar cells to work beautifully here, they will work anywhere.”

BACTERIAL BUILDING BLOCKS

With rising sea levels threatening to claim vast swathes of land, finding a way to sustainably protect at-risk coastal cities while encouraging marine biodiversity is a critical research problem. The solution may lie in dense, solid bacterial aggregates known as biofilms.

NTU microbiologist, Scott Rice, became interested in biofilms because of their effects on the species that form them. “When bacteria grow as a biofilm, they show increased resistance to anti-microbials,” says Rice, “and they also become much more tolerant of other stresses.” Biofilm formation is common among bacterial species, and can make disease-causing microbes even more dangerous as a consequence of enhanced drug resistance. But it can be beneficial in marine environments, where it creates a supportive environment for

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other organisms such as corals, kelp, and sponges, to gather.

Rice's research is focused on understanding how diverse marine bacteria come together as biofilms, and how their behaviour changes as a consequence. "These communities are highly functionally cooperative in many cases," he says, noting that different species can collaborate to produce chemicals that fend off pathogens, eliminate toxic compounds, and recruit other organisms to further build the community. "There's some suggestion that bacteria produce cues that some algal species recognize and preferentially settle there, as well as tubeworms and other species."

By understanding how this recruitment occurs, Rice and his colleagues hope to leverage the same process to build marine ecosystems. For example, Singapore is preventing the loss of land due to erosion and rising ocean levels through the use of sea walls. These are typically bare concrete structures or made from natural stone materials, e.g. granite, which are not readily colonized, but they could potentially be transformed by seeding with biofilm-forming bacteria that draw in algae and promote coral formation. "By increasing the density of organisms on these structures you also then increase the local diversity within that sort of near-shore marine system," says Rice. His findings suggest that the particular species involved may actually be less important here than having a structural environment that supports bacterial growth in general.

Post-fermentation prawn shells and powder with enriched chitin/chitosan.

Enrichment of chitin/chitosan from prawn shells by fermentation.

PLASTICS FROM PRAWNS

No matter how enthusiastically you finish a plate, every meal generates waste, such as the peels and rinds of fruit and vegetables. But NTU food scientist, William Chen, knows that there are valuable resources concealed within this so-called waste, just waiting to be extracted and put to use.

Chen notes that rising affluence in Southeast Asia is driving the growing demand for seafood. Accordingly, his group recently began working on techniques for extracting chitin and the related compound chitosan from the discarded shells of prawns and other shellfish. Like cellulose, chitin is a durable and versatile carbohydrate with many applications in manufacturing as well as biomedical engineering. "Traditionally, people have used a very strong chemical treatment to take it out of the prawn shell," he says. "But then you generate other types of chemical waste, and the chitin that comes out tends to be of lower quality."

Bacterial fermentation could provide a solution. Chen's group has identified microbial species that produce acids that safely break down minerals in the shells as well as enzymes that degrade shellfish proteins—with the whole reaction fuelled by by-products from fruit waste. After removing the chitin from the fermentation reaction, the remaining materials are sufficiently safe and nutrient-rich to be used as agricultural fertilizer.

The extracted chitin can subsequently be used to make durable biodegradable plastics that offer a more sustainable and robust substitute for current petroleum-based products. Chen's team recently received funding from the Temasek Foundation to further advance the commercialization of this process. "If we can work with existing manufacturers, I think the pricing of these biodegradable plastics can be competitive," he says. He envisions this approach as a generalizable platform technology that could be effective for recovering materials from other food waste, such as banana peels or sugarcane remnants.

These three research programs are a small part of NTU's broader efforts to mitigate human impact on the environment and build a sustainable future for the planet. "This is a way to connect academia to society, so that the world can see that academic research can be very meaningful," says Chen, "and that innovation will not stay on a shelf at the university, or in a professor's drawer." ■