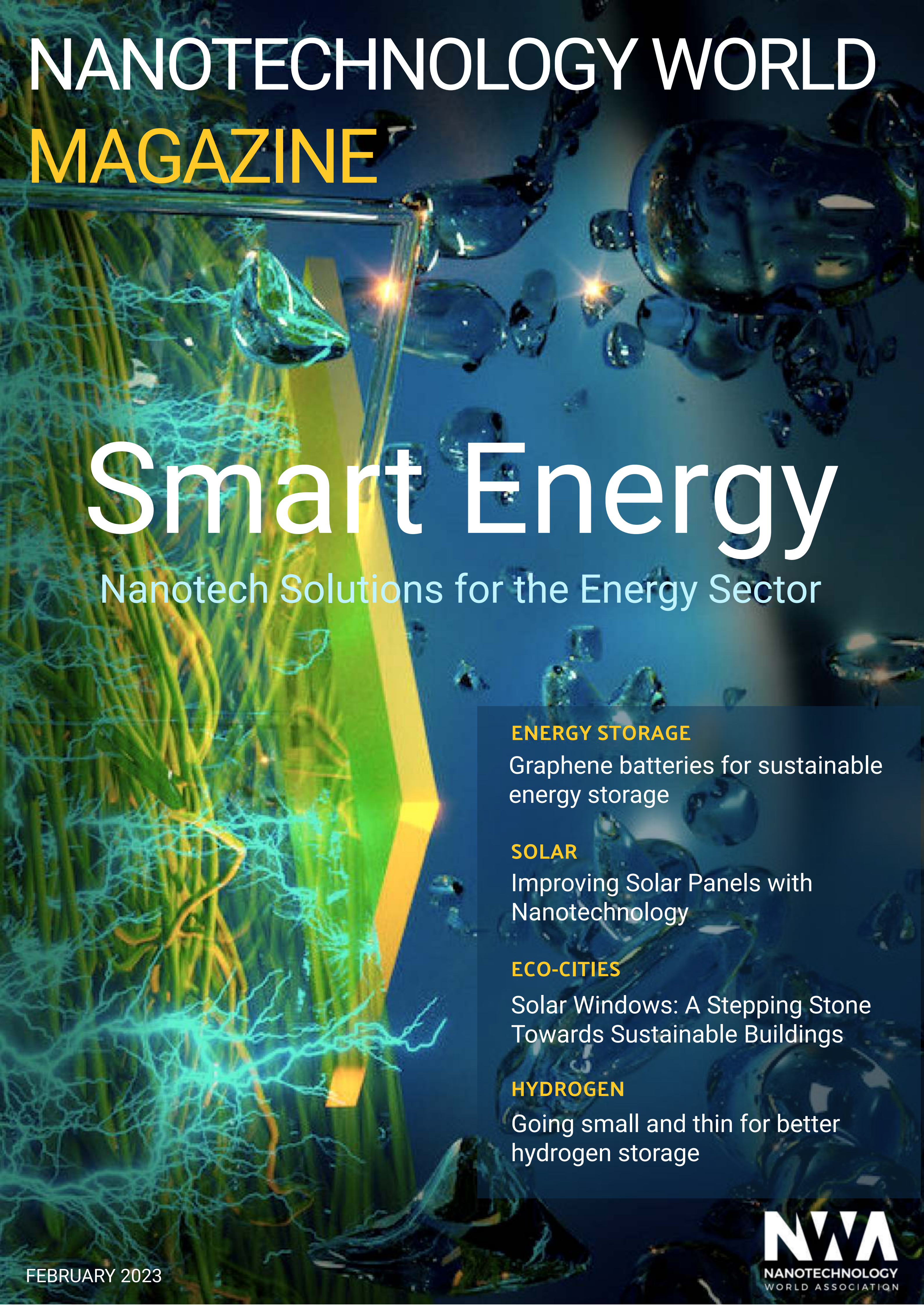

NANOTECHNOLOGY WORLD MAGAZINE

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Going small and thin for better hydrogen storage

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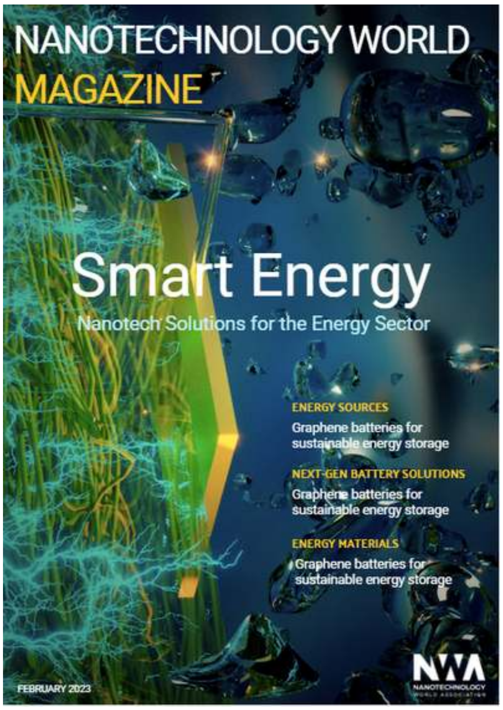

Nanotechnology World Magazine
February 2023

Nanotechnology is being used in the energy sector to develop new and improved energy technologies, such as more efficient solar cells, better batteries, and more durable fuel cells.

Cover image:
A thin film of protein nanowires generating electricity from atmospheric humidity. UMass Amherst researchers say the device can literally make electricity out of thin air. Credit: UMass Amherst/Yao and Lovley labs

Next issue: May 2023

Nanotechnology in Electronic Devices and Data Storage

FEATURES

Nanotechnology and the future of energy

Nanotechnology has been a game changer in many industries, and the energy industry is no exception. Access to lighter, more reliable, durable and efficient wind turbine blades and photovoltaic panels has already been granted by nanomaterials used in energy conversion technologies.

Imaginative researchers are finding ways to push the boundaries of nearly every aspect of energy storage, allowing smaller batteries to store more energy for longer cycles, charge faster, last longer thanks to reduced cycle decay; becoming safer from the risk of fiery explosions, and using materials that are more environmentally friendly.

Introduction of strong and highly conductive nanomaterials are also paving the way to reducing our dependency on critical minerals and their supply chains.

The wish of tapping into hydrogen's potential is starting to come true as new materials are opening the door to significant increases in its volumetric energy density storage without requiring extreme pressures or temperatures.

Biofuels are also being transformed in various ways: via more efficient and durable membranes and filters; immobilized enzymes which are more stable and efficient – or perhaps entirely replaced by enzyme mimics which can also be even more efficient and cheaper; its combustion can be improved with the addition of nano additives which can act as catalysts, while nano lubricants help increase engines' performance and durability. New types of biofuels altogether are emerging from the creation of new types of algae, or even of new bacteria that are better at breaking them down.

Even the more conventional oil and gas drilling can leverage nanotechnology to help tap into previously inaccessible reserves.

As the future brings with it an increasing demand for energy, nanotechnology will be there to continue to push the limits on the many ways we generate, store and use energy.

Marine Le Bouar
Founder and CEO, Nanotechnology World Association
Editor in Chief, Nanotechnology World Magazine

UPCOMING EVENTS

Japan Energy Summit & Exhibition
February 28 - March 2nd, 2023
Tokyo, Japan

Middle East Energy Dubai
March 07 - 09, 2023
Dubai, UAE

Enlit Australia
March 22 - 23, 2023
Melbourne, Australia

Latin America Energy Summit 2023
April 19 - 20, 2023
Santiago, Chile

WindEurope 2023
April 25 - 27, 2023
Copenhagen, Denmark

Battery Conference
April 27 - 28, 2023
Aachen, Germany

World Hydrogen 2023 Summit & Exhibition
May 9 - 11, 2023
Rotterdam, Netherlands

The Battery Show Europe
May 23 - 25, 2023
Stuttgart, Germany

AUSIREC 2024
April 16 - 18, 2024
Abu Dhabi, UAE

World Future Energy Summit 2024
April 16 - 18, 2024
Abu Dhabi, UAE

Graphene batteries for sustainable energy storage

Akanksha Urade, Ph.D. Candidate at IIT Roorkee and Graphene & 2D Materials Communicator

Lithium-ion batteries (LIBs) are an integral part of our modern world, powering computers, smartphones, and even electric vehicles (EVs). However, the current generation of LIBs will not be able to keep their dominant position for a long time as it is hitting its theoretical limits. As a result, one focus of current research has been on developing materials with more desired properties for use in batteries. One such material is graphene, a sheet of carbon atoms that is one atom thick and arranged in a honeycomb pattern. This article will discuss how improvements in graphene batteries offer considerable promise for the next-generation energy industry.

The Decline and Fall of Lithium-ion Batteries

LIBs primarily consist of four components including a lithium metal oxide like lithium cobalt oxide as a cathode that supplies the lithium-ions, lithium-graphite compounds as anode, separator and an organic electrolyte [Fig. 1]. The lithium-ion batteries provide power through the movement of positively charged lithium ions.

While LIBs are the most efficient rechargeable batteries available commercially, one difficulty that they continue to have is their low power density and thus long recharge durations (usually hours), whereas battery customers want batteries that can recharge quickly, perhaps even in a few minutes or seconds.

Another issue with LIBs is their long-term viability. The majority of LIB components are not biocompatible, making the recycling procedure prohibitively expensive. Finally, and perhaps most importantly, there are safety concerns with LIBs. The liquid within a lithium-ion battery is extremely flammable. Any damage to the battery's outer layers can cause a short circuit, which can end in fire and explosion.

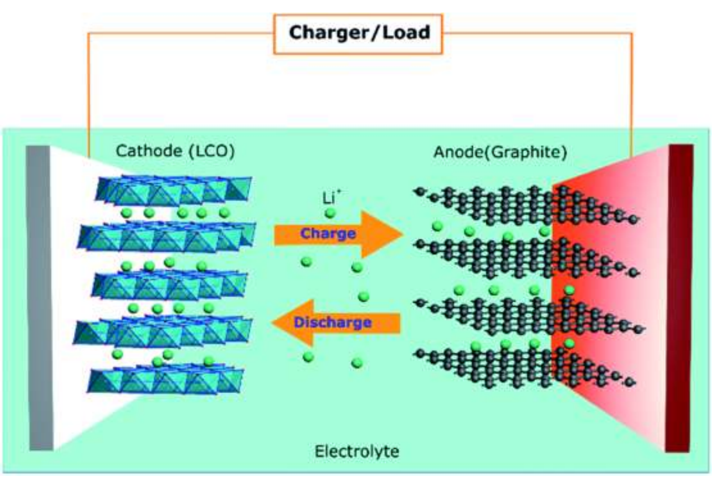

Fig. 1. *Schematic diagram of LIBs cell Ref. [1]*

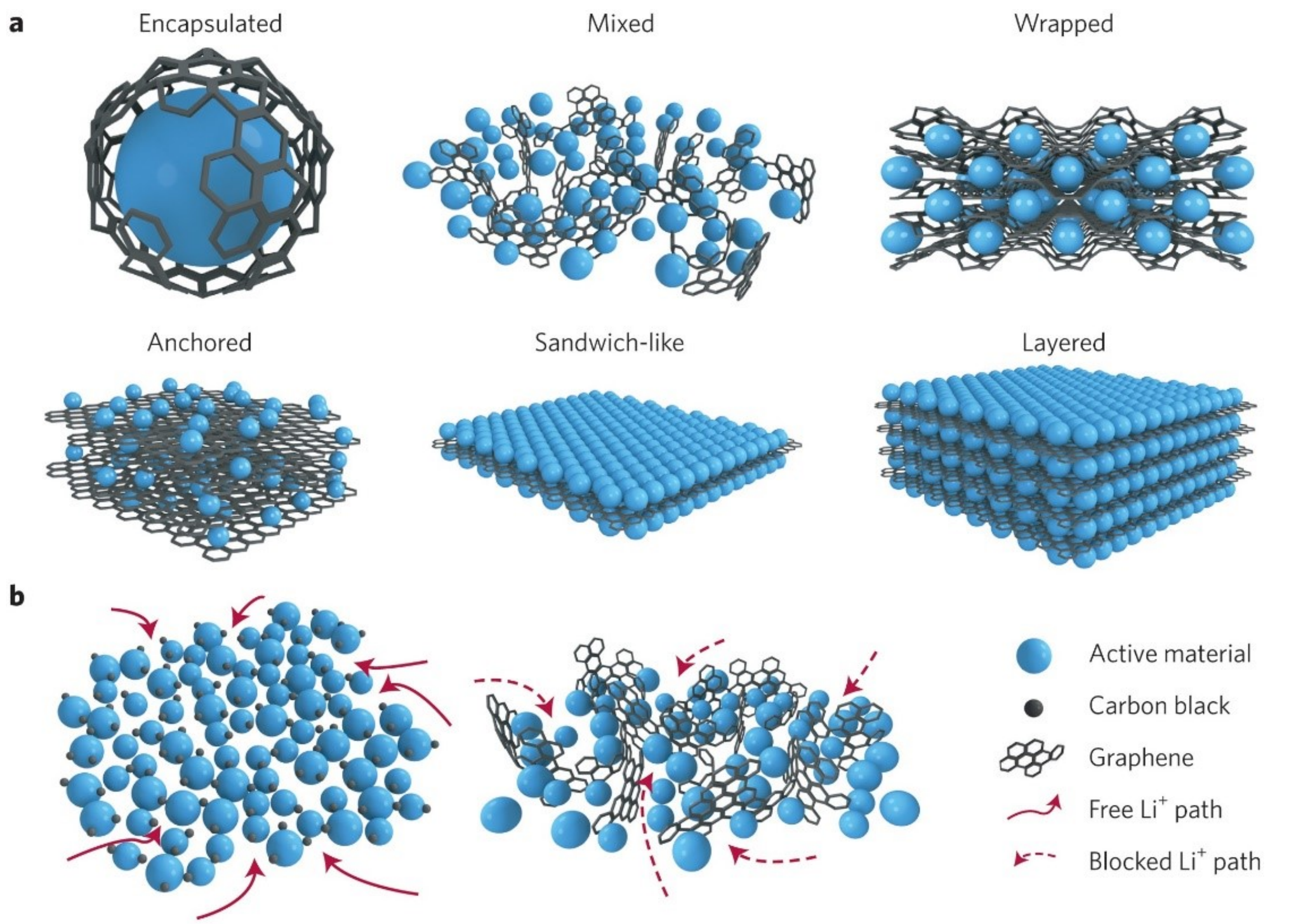

Fig. 2. *Schematic of the different structures of graphene composite electrode materials Ref. [4].*

Graphene: A promising Solution in New Battery Technology

Graphite is currently used as an anode material in LIBs; however, it does have its limitations. In graphite, to hold just one lithium ion, graphite needs six carbon atoms. This relative weakness restricts how much lithium electrodes can hold onto, which in turn limits how much energy the battery can store. A graphene nanosheet, unlike graphite, may absorb lithium ions on both faces of the sheet, along its edges, and even in the defects site. This results in a theoretical capacity of 744 mA h/g, compared to 372 mA h/g for graphite.

While charging, the lithium ions are moved from the cathode to the anode via the electrolyte. During this travel, the lithium ions are covered by the solvent molecules in the electrolyte. When the lithium ions and solvent molecules reach the graphite (anode), they react with it to form a layer known as the solid electrolyte interface (SEI). The formation of this SEI layer prevents electrons from making direct contact with the electrolyte, protecting the electrolyte from degradation and the resulting short circuit between the anode and cathode, which could lead to a fire or explosion.

The formation of the SEI layer on the anode of a LIB depends on the surface area of the anode material, making the surface area a crucial characteristic of electrode material. Compared to graphite, which has a surface area of 10 m^2/g, graphene's surface area is 2630 m^2/g, meaning that more Li ions can be consumed by graphene to form a stable SEI layer on the electrode.

Another reason for the excitement surrounding graphene is its excellent physical properties, which include high electron mobility (2×10^2 cm^2/Vs) and high thermal conductivity (~3×103 W/mK). As a result, using graphene allows for faster electron and ion transport in the electrodes, controlling the rate at which the battery can be charged and discharged [2]. Researchers have shown that such batteries are possible by replacing the graphite anodes found in conventional LIBs with graphene electrodes [3].

This has resulted in LIB anodes with specific capacities of more than 1,000 mAh/g, which is more than three times the capacity of standard graphite electrodes and with a short charging time of a few seconds/minutes. It should be noted that graphene cannot be used as a direct replacement for the current graphite cathode/anode in Li-ion batteries. Graphene, on the other hand, can play a critical role when used as a matrix in the composite lithium cathode material [shown in Fig. 2].

Graphene to Reduce Li-Ion Battery Fire Risk

The tendency of LIBs to catch fire, also known as a thermal runway, is well known; it occurs most frequently when the batteries overheat. Under these conditions, the battery temperature rises, causing the organic electrolyte to decompose and release flammable gases. As a result, the cathode inside the battery, which is typically lithium cobalt oxide, decomposes and loses its lattice oxygen. The released oxygen has the potential to ignite the flammable gases, resulting in a thermal runaway or explosion. Due to the fact that graphene sheets are flexible, strong, electrically conductive, and most importantly impermeable to oxygen atoms, they are the perfect material for preventing the release of oxygen into the electrolyte. Scientists demonstrated that wrapping small particles of a lithium cobalt oxide cathode in graphene sheets prevents oxygen from escaping and hence resulting thermal runway [5].

Getting Closer to Commercialization

One of the primary reasons consumers select one smartphone over another is not the processor or the amount of data storage, but the battery life. Recent advancements in graphene research bring us closer to what is arguably the most important feature of all: batteries that last longer.

For example, scientists from the National Aeronautics and Space Administration (NASA), have developed a graphene-based LIBs battery that is safer, lighter, and performs better than commonly used LIBs for electric aircraft [6]. The battery uses an inexpensive nonflammable electrolyte, a cathode made up of a combination of sulfur and selenium, whose particles are arranged in a graphene mesh and a lithium-metal anode. According to the reports, the battery can operate at 105°C temperature, almost twice as hot as LIBs, without any cooling system. The battery reportedly has an energy density of 500 Wh/kg. For comparison, Tesla's LIB can offer right now about 260 Wh/kg with lots of cooling systems.

Additionally, industries are attempting to replace the conventional graphite anode with silicon because of its high theoretical capacity (4200 mAh/g). However, the silicon anode expands by more than 300 percent during charging and discharging, causing its surface to crack and energy storage performance to rapidly decline. When graphene and silicon are combined in the anodes of LIBs, it not only reduces silicon expansion and contraction but also improves electron and lithium-ion transport capability.

In comparison to other contemporary battery technologies, aluminum-ion batteries (AIBs) stand out thanks to their

Projected global annual transportation energy storage deployments

U.S. Department of Energy

Fig. 1 *Projected global annual transportation energy storage deployments*

SLI applications exclusively lead–acid today, currently dominate the transportation market as they are used with all types of vehicles—internal combustion engine vehicles, xEVs, and FCEVs. They are expected to grow slowly through 2030, following global vehicle sales.

Annual mobility storage deployments, which are currently a fraction of SLI, will likely exceed SLI for the first time in 2023, with explosive growth expected through 2030.

Mobility storage includes both onboard battery and hydrogen storage. Storage on battery electric vehicles and plug-in hybrid vehicles is dominated by lithium-ion batteries.

Hybrid electric vehicles can employ other battery chemistries such as nickel metal hydride. Figure 1 summarizes the projected growth of the transportation sector.

Source:
Energy Storage Grand Challenge: Energy Storage Market Report
U.S. Department of Energy

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inexpensive cost and the high gravimetric capacity of the Al anode (2980 mAh/g). Researchers at the University of Queensland in Australia have begun a scale-up study of the AIBs in conjunction with the Graphene Manufacturing Group [7]. The cathode material of the prototype coil cell is graphene, and the anode material is aluminum. The battery has an impressive energy density of 150–160 Wh/kg and only needs 1–5 minutes to be fully charged.

The electric vehicle (EV) industry is searching for a more environmentally friendly raw material to replace cobalt in LIBs, as global sales of EVs are continuously doubling. One such battery is lithium-sulfur batteries, which have been hailed for a long time as sustainable batteries due to sulfur's natural abundance and chemical structure that allows it to store more energy [8].

The main issue with lithium-sulfur batteries in real-world applications is the occurrence of soluble polysulfide species during discharge cycles. These polysulfide species diffuse between the cathode and anode and may induce an internal short circuit. This phenomenon, known as the shuttling effect, is accountable for the rapid capacity fading and poor efficiency of lithium-sulfur batteries. Researchers discovered that they could achieve an energy density of ~900 Wh/kg, which is nearly three times that of conventional LIBs, by adding a graphene membrane to the sulfur cathode. This membrane served as an efficient separator and reduced the rate of cyclic capacity decay.

Looking Ahead to the Future

Graphene's exceptional electrochemical properties combined with high electrical conductivity, excellent mechanical properties, and large surface area have irrevocably altered the landscape of energy storage. Considering the ongoing commercialization of graphene, it is anticipated that graphene battery research will continue to expand rapidly over the next decade, with the promise that it will undoubtedly fill a number of gaps where existing battery chemistries have struggled to be effective.

References page 52

EV Battery Giant CATL To Adopt Toyocolor's Battery Materials

Toyocolor Co., Ltd., the colorants and functional materials arm of the specialty chemicals company Toyo Ink Group of Japan, today announced that the company's Lioaccum™ conductive carbon nanotube (CNT) dispersions has been selected by the world's largest battery manufacturer CATL (Contemporary Amperex Technology Co., Limited) for use in CATL's next-generation high capacity li-ion batteries (LiB). Lioaccum CNT dispersions are scheduled for installation into mass-produced vehicles beginning 2024.

With governing bodies around the world tightening emission restrictions on gas-powered vehicles in an effort to achieve carbon neutrality, the percentage of EVs in the new vehicle market is expected to jump from 8% in 2022 to 30% in 2030. China's EV market, one of the three largest automobile markets in the world, is broadly divided into the sub-markets of budget models for running short distances and high-end models that require longer cruising ranges. High-capacity LiBs are critical to extending cruising range for high-end vehicles.

The Lioaccum dispersion adopted by CATL is a key material that contributes to the expanded capacity and energy density of LiBs through the adoption of highly conductive CNTs. While the stable distribution of high-performance carbon nanotubes was once considered difficult to accomplish, Toyocolor succeeded in applying its proprietary dispersion technology to overcome technical hurdles and achieve highly stable CNT dispersions of high quality.

In line with CATL's supply needs, the Toyo Ink Group will be expanding the capacity of its dispersion production base, Zhuhai Toyocolor Co., Ltd., in Guangdong, China. Lioaccum dispersions manufactured here are expected to be incorporated into mass-produced vehicles beginning 2024. **Read more**

US

DOE Awards Sila $100 Million to Scale Manufacturing of its Next-generation Anode Materials

DOE announced it has awarded Sila, a next-generation battery materials company, $100 million to fund the build-out of its 600,000+ square foot facility in Moses Lake, WA

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MIDDLE EAST

Saudi Arabia moves on $5bn hydrogen project

Design and early works are now underway for Saudi Arabia's $5bn Helios Green Fuels project, an industry source tells MEED.

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ASIA

Mitsubishi to build $251m waste-to-energy plant in Japan

The 33.15 billion yen ($251.2 million) contract will include long-term operation and maintenance services for 20 years from Mitsubishi, which won the contract through a competitive bidding process initiated by the association.

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EUROPE

New fusion energy prototype to be built in UK

A new fusion energy advanced prototype with power plant-relevant magnet technology will be built in the UK by Tokamak Energy.

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US

Biden-Harris Administration Announces Nearly $350 Million For Long-Duration Energy Storage Demonstration Projects

$350 million for emerging Long-Duration Energy Storage (LDES) demonstration projects capable of delivering electricity for 10 to 24 hours or longer to support a low-cost, reliable, carbon-free electric grid.

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ASIA

China launches 100-mph hydrogen/supercapacitor train

The four-car train is capable of 100 mph (160 km/h), making it the fastest hydrogen train to date.

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HoSt Group expands and bolsters its renewable gases technology portfolio with hydrogen technology by acquiring HyGear, a subsidiary of Xebec Adsorption Inc.

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Improving Solar Panels with Nanotechnology

Nichole Cates, Brenna Tryon, Lauren Micklow, Stephen Furst
Smart Material Solutions, Inc.

Nanoscale textures can help solar panels harvest more light and prevent dust contamination, leading to meaningful improvements in energy production.

What is a solar panel?

Solar panels capture sunlight and convert it into electricity that can power our electronics, houses, and cars without consuming fossil fuels or emitting carbon. The more light a panel absorbs, the more electrical power it can produce. Ideally, a solar panel will absorb all incident sunlight, rendering it completely black. To do this, all incoming light must enter the panel and be trapped there until it is completely absorbed by the photoactive material within the cell. In reality, some light is not absorbed because it reflects off the panel, is blocked by particles like dirt, or escapes the panel before being absorbed.

Nanoscale features such as moth-eye coatings, light-trapping features, and plasmonic structures can reduce reflections and confine light inside the solar panel so that more light is absorbed and converted into electricity. Many of these nanopatterns also act as self-cleaning or dust-mitigating surfaces that prevent the buildup of dust, dirt, and pollen that can block incoming light and decrease efficiency.

Moth-eye features decrease reflections

Moth-eye features mimic the nanoscale structures on the surface of moths' eyes

that prevent them from reflecting light at night, so that they do not stand out like a deer's eyes glowing in headlights. Moth-eye features are smaller than the wavelength of light, so they can trick light into believing that the transition from air into another material is gradual. This gradual change eases light's transition into the material and thus reduces the reflection from the surface. In more scientific terms, a smooth surface has an abrupt change in the effective refractive index that causes reflections, but moth-eye features result in a more gradual change in the effective refractive index such that less light reflects.

Figure 1 illustrates how moth-eye features reduce the reflected light, thereby increasing the amount of light that enters the panel where it can be absorbed. Theoretically, perfect moth-eye features can completely eliminate the reflection off the top surface, allowing 100% of the incident light to enter the panel. Unlike traditional anti-reflective coatings that rely on light interference and therefore work well for only certain colors of light, moth-eye coatings work well for a wide range of colors and incidence angles. Unfortunately, this same phenomenon will also allow light that has traveled through the panel to escape more easily. As a result, anti-reflective coatings such as moth-eye nanofeatures are often combined with light-trapping microfeatures that confine light inside the solar panel.

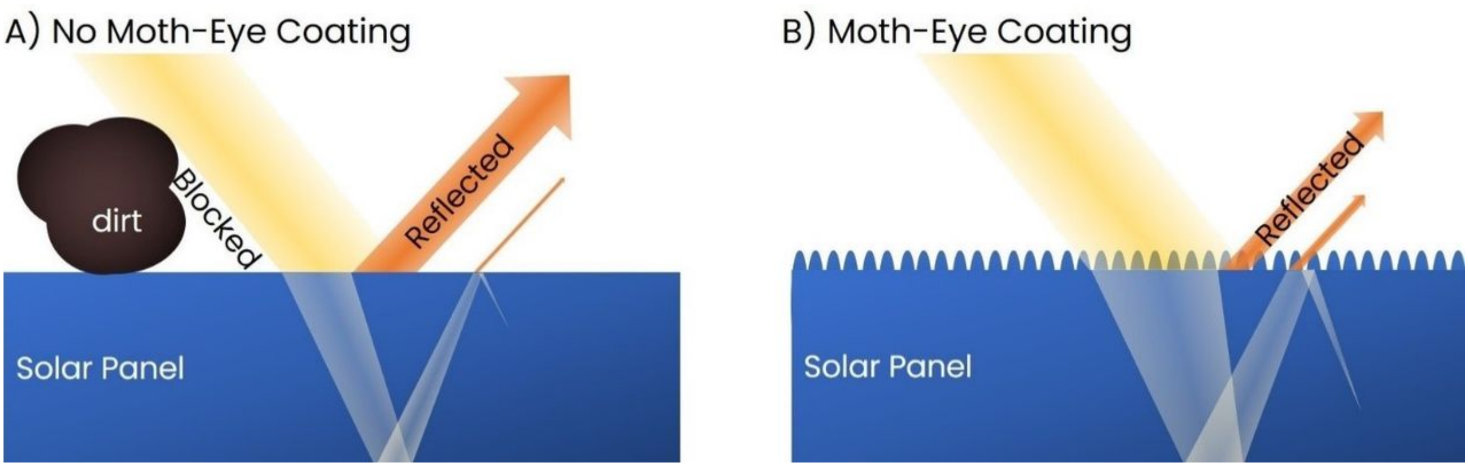

Figure 1: *Illustration of light interacting with a solar panel without (A) and with (B) a moth-eye coating. Incoming and reflected light are shown in yellow and orange, respectively.*

Light-trapping features increase absorption

Light-trapping features redirect light to increase its chance of being absorbed by a solar panel. These microscale features are larger than moth-eye nanofeatures and redirect light according to ray optics – the same physics that describes how a camera lens focuses light. Properly designed light-trapping microfeatures increase the amount of light a solar panel absorbs by increasing its path length inside the panel, giving reflected light a second chance at being absorbed, and decreasing reflection of light when the solar panel does not directly face the sun.

Increasing optical path length

Optical path length is the distance light travels in a material, in this case the light-absorbing material of a solar panel. Figure 2A shows a solar panel without light-trapping features where the optical path length is slightly more than twice the panel thickness. Light-trapping features like those illustrated in Figure 2B can bend, scatter, or diffract light to increase its optical path length and thus increase its chance of being absorbed by the solar panel. Although Figure 2 shows light-trapping features on top of the solar panel, similar features on the reflective back surface can also scatter light to increase its optical path length.

If light is redirected to a shallow enough angle, it can undergo total internal reflection so that all the light inside the panel is internally reflected. This enables the light to make multiple passes back and forth inside the panel and results in an optical path length that is many multiples of the panel thickness. For a random texture on the top surface, the Yablonovitch limit predicts a maximum optical path length (OPL) of about 50 times the panel thickness for silicon solar panels (maximum OPL = $4n^2$ * thickness, where n is the refractive index). Periodically arranged structures like diffraction gratings and photonic crystals can overcome this limit and achieve even higher optical path lengths due to the excitation of resonances.

Capturing reflected light

Light-trapping features can also increase absorption by capturing reflected light. For example, inverted microscale pyramidal features like those illustrated in Figure 2B enable light that is initially reflected to enter the solar panel through an adjacent inverted pyramid, thus decreasing losses from reflection.

Reducing reflection when panels do not directly face the sun

Finally, light-trapping features can decrease reflection when a solar panel is not directly facing the

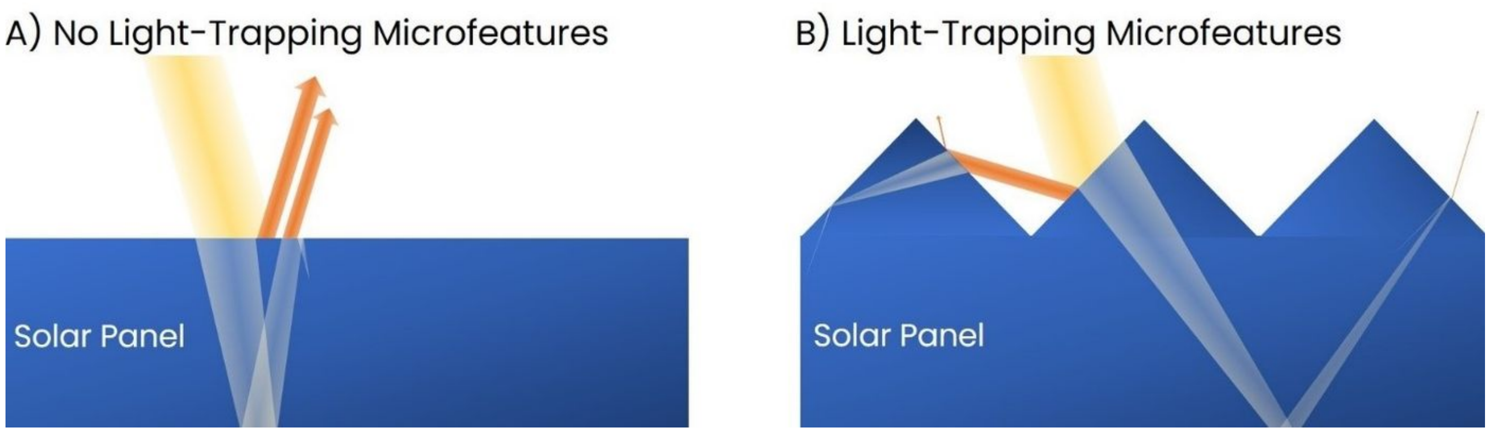

***Figure 2:** Illustration of optical path length in solar cells without (A) and with (B) light-trapping microfeatures. Incoming and reflected light are illustrated in yellow and orange, respectively.*

incoming light, such as when the sun is low in the sky. The Fresnel equations predict high reflection when the incidence angle, θ, is large. Figure 3 shows how light-trapping microfeatures can reduce this reflection, since light with a large incidence angle relative to the surface of the solar panel can have a small angle relative to individual microfeatures. As a result, light-trapping microfeatures can dramatically increase the amount of light a solar panel absorbs when the incidence angle is large.

Plasmonic structures redirect and confine light

Plasmonic structures can also scatter light and confine it inside a solar panel, although they function very differently from the light-trapping microfeatures discussed above. Plasmonic structures consist of nanoscale metal structures, often in the form of patterned metal films or metal nanoparticles. These structures manipulate light by causing the electron cloud inside the nanoscale metal to oscillate. These plasmonic structures can be added on the top, middle, or back reflector of a solar panel to scatter light, increase its optical path length, promote total internal reflection, and act as antennas that concentrate light inside the panel. Well-designed plasmonic structures therefore make it easy for light to enter and hard for it to leave a solar panel.

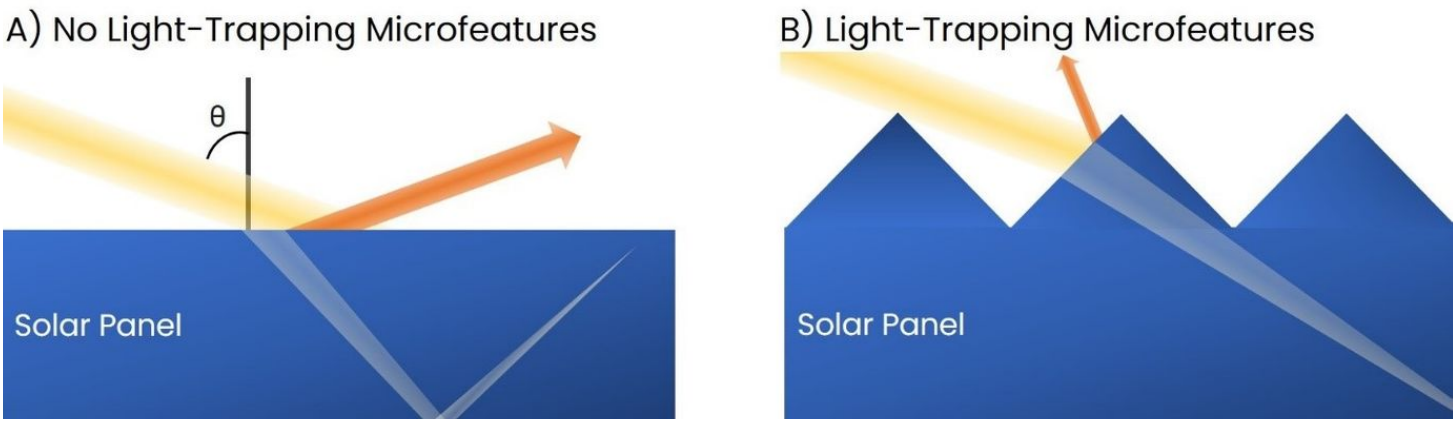

Figure 3: *Illustration of how sunlight with a large incidence angle, θ, interacts with a solar panel without (A) and with (B) light-trapping microfeatures. Incoming and reflected light are illustrated in yellow and orange, respectively.*

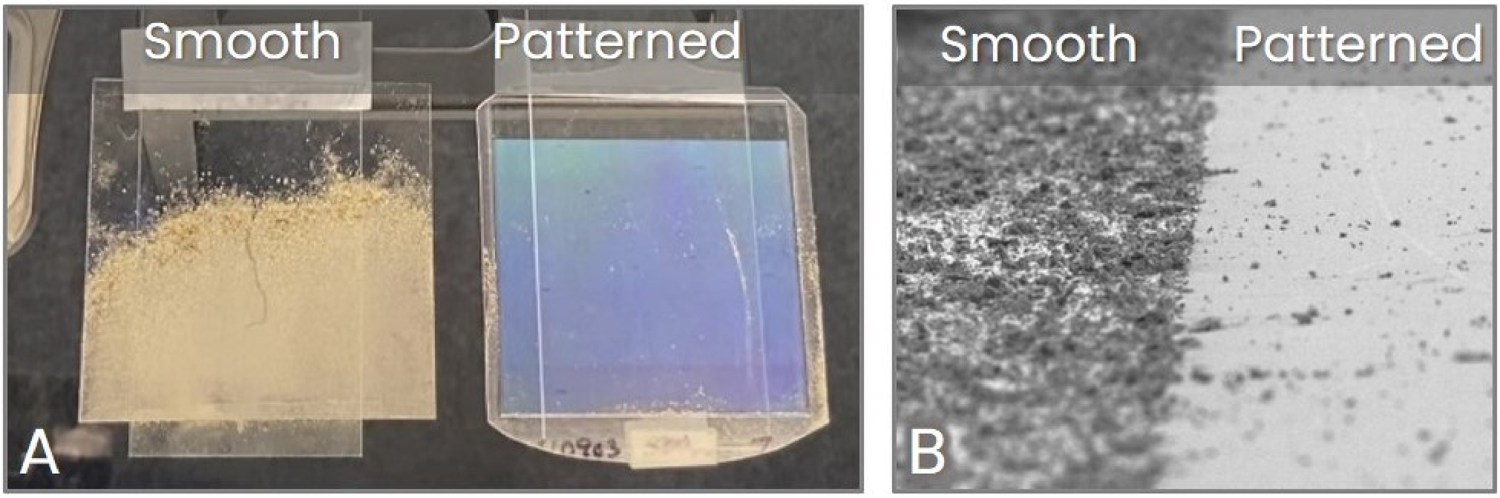

Figure 4: *Dust-mitigation properties of nanopatterns demonstrated with a photo comparing a smooth (left) and nanopatterned (right) film of the same material after covering with dust and tilting to remove dust with gravity (A) and an SEM image showing the seam between a smooth (left) and nanopatterned (right) film that has been exposed to dust. In both cases, the smooth film is covered with dust, whereas the patterned film is largely free of dust.*

Nanostructures have anti-fouling properties

The buildup of dirt, dust, grime, and sand that blocks incoming light is a big problem for solar panels. In fact, the buildup of dust on the solar panels of Mars rovers often reduces available power or shuts them down. Occasionally, a Martian windstorm will blow away the dust and revive a rover by renewing its access to solar power. On Earth, cleaning of solar panels is often needed, especially in desert environments that lack rainfall.

Fortunately, many moth-eye and light-trapping nano- and microfeatures also make surfaces dust-mitigating and anti-fouling. The lotus effect, named for the nanoscale features that make lotus leaves self-cleaning, decreases particle adhesion to a surface by decreasing the contact area. Nanostructures can also make surfaces superhydrophobic, making it easier for rain to wash away any particles that do buildup.

Smart Material Solutions, Inc. and Professor Chih-Hao Chang's group at UT Austin recently created nanopatterns that significantly decrease the adhesion of Lunar dust for a NASA-funded project (Figure 4). This is great news for solar panels both in space and on Earth!

Solar research at Smart Material Solutions

Smart Material Solutions, Inc. (SMS) recently won the Army XTech Clean Tech Competition and a Phase I Small Business Innovation Research (SBIR) grant to use nanocoining and R2R NIL to manufacture light-trapping, self-cleaning coatings that increase the efficiency and reliability of thin-film solar panels. Thin-film solar panels can be lightweight and flexible, making them easy to transport and deploy. SMS will increase the performance of these solar panels by adding nanopatterns like those shown in Figure 5 to solar panels and demonstrating their light-trapping and anti-fouling properties. After the creation of prototypes in Phase I, SMS plans to partner with a solar company to roll-to-roll manufacture panels with self-cleaning, light-trapping coatings during Phase II of the project.

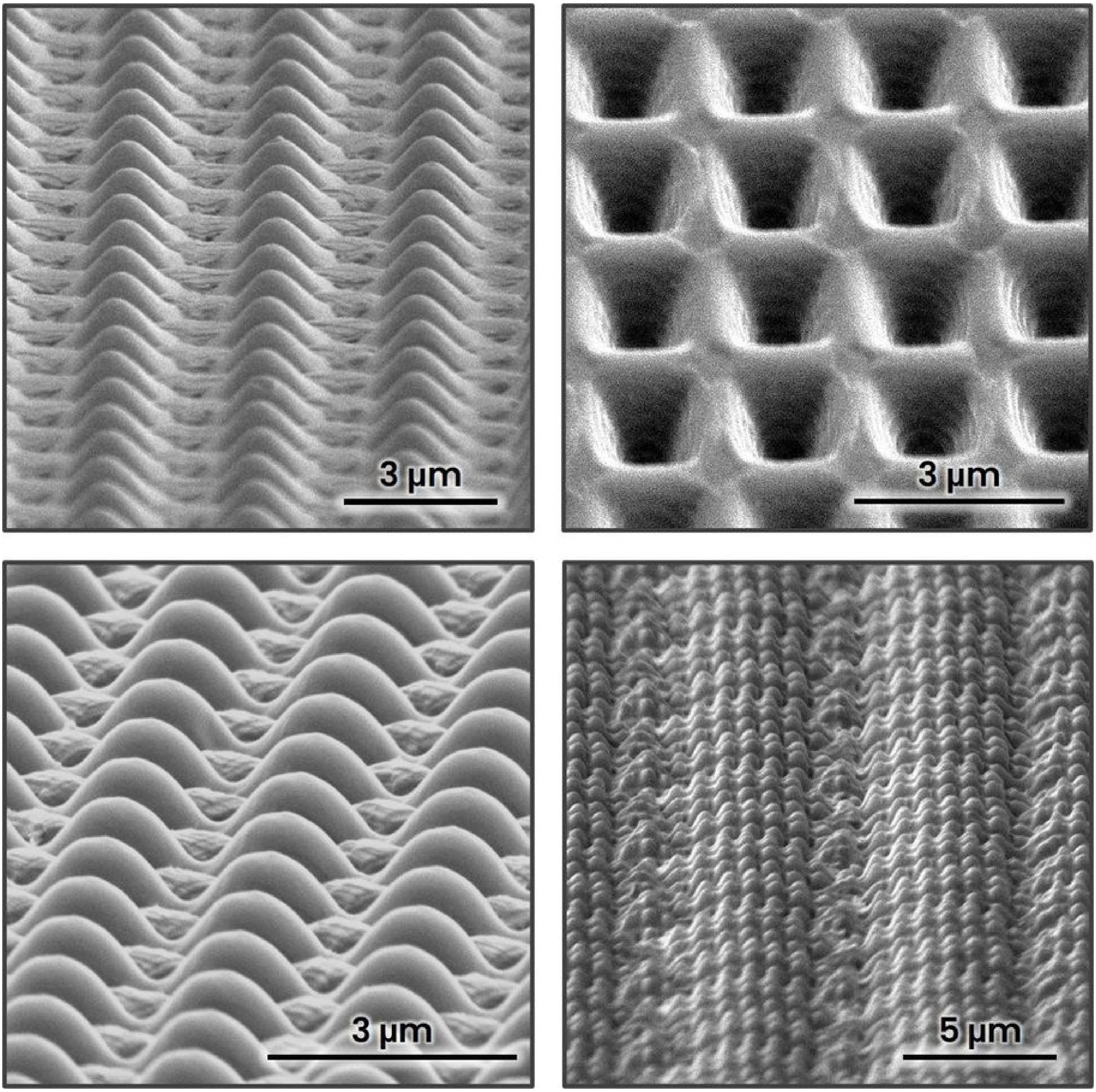

Figure 5: *Light-trapping microfeatures patterned in polymer using nanocoining and nanoimprint lithography at SMS include pyramids, inverted pyramids, microlens arrays, and hierarchical features with nanofeatures on top of microfeatures.*

Research News

Stanford scientists illuminate barrier to next-generation battery that charges very quickly
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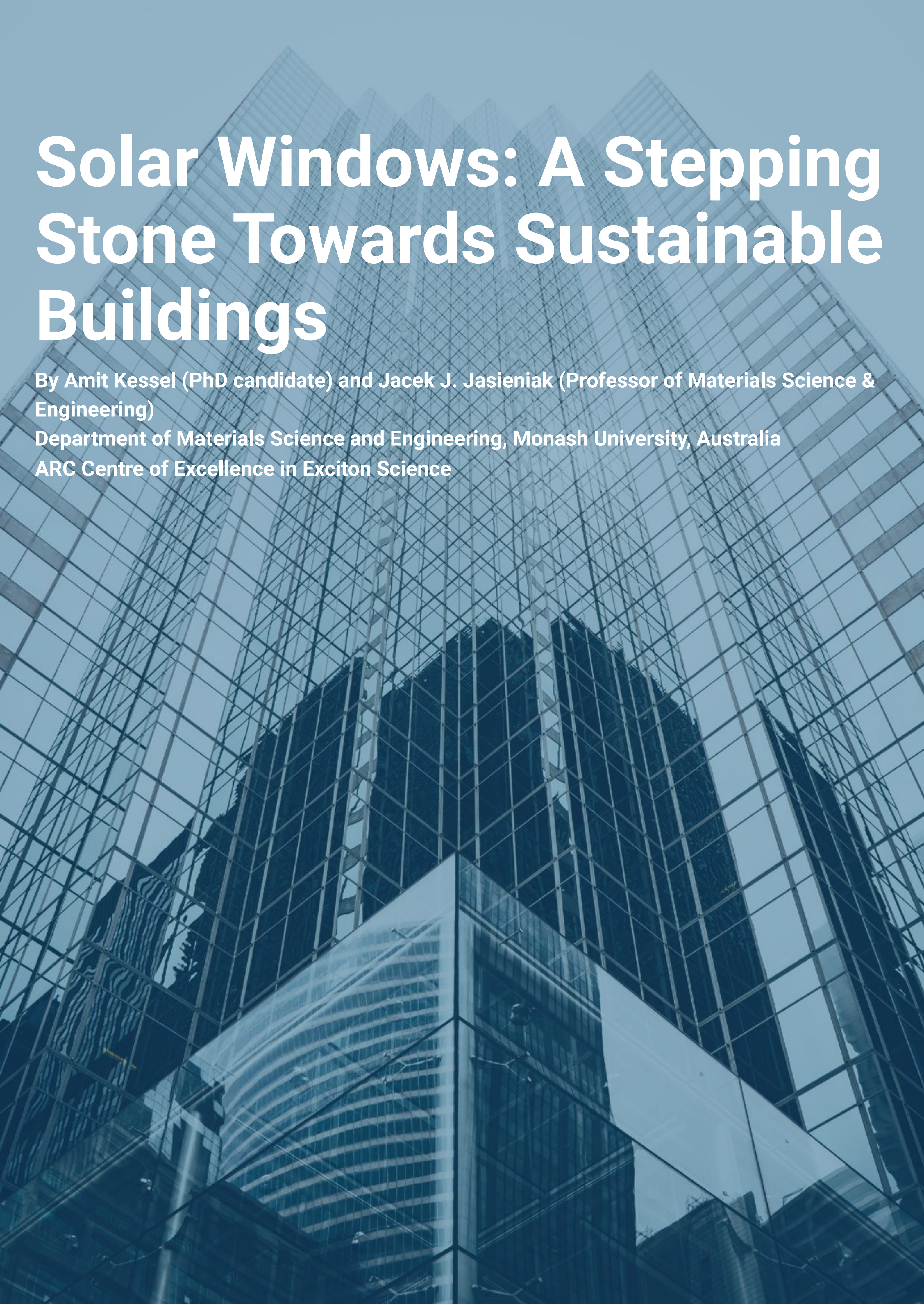
Solar Windows: A Stepping Stone Towards Sustainable Buildings

By Amit Kessel (PhD candidate) and Jacek J. Jasieniak (Professor of Materials Science & Engineering)
Department of Materials Science and Engineering, Monash University, Australia
ARC Centre of Excellence in Exciton Science



Photovoltaics (PV) serve as a key technology to enable a sustainable energy future by converting sunlight - the world's most abundant renewable resource - into electricity. For the most part, global PV deployment is dominated by residential rooftop installations and large-scale PV power plants. Over the past five years, annual PV Installation have tripled, with rooftop share rising to 43% of the installed capacity [1]. As mass urbanisation unfolds, population densities are set to progressively increase. In response, cities are evolving through the construction of taller buildings, which brings about a major growth in local energy demand [2].

While conventional approaches consider rooftops for PV deployment, building facades can also receive large amounts of sunlight. This is particularly true for tall buildings, where the façade area is high. A recent study suggests that 76% percent of the electricity demands of the city of Melbourne, Australia, could in principle be met via optimised PV deployment, with 12% of the electricity coming directly from the walls and windows of the buildings via appropriately integrated PV technologies [3]. With modern architectural trends moving towards fully glazed tall buildings, a growing opportunity for solar windows technologies is emerging.

Here, we discuss the technical considerations to realize a useful PV window, present the leading technologies, and provide an outlook for the future evolution of the solar windows market.

Solar window technologies

A solar cell is a device that converts light to electricity. The entire ultraviolet, visible, and parts of the near infrared light spectrum of the sun are converted to achieve efficient devices. For crystalline silicon PV, which is the most dominant PV technology in the world, record power conversion efficiencies (PCE) of 26.1% have been reported. Integrating PV modules within windows requires a suitable level of transparency (typically 30-70%). This naturally reduces the potential PCE of any integrated PV, as the photons that are being transmitted do not contribute to the generated power output. At a first approximation, the drop in PCE compared to an opaque cell is proportionate to the level of transparency. Beyond efficiency, the level of optical clarity and colour are also key parameters that need to be considered.

There are three main PV window architectures: Selective Absorber, Semi-Transparent, and Semi-Opaque solar cells.

Selective Absorber

Ultraviolet (UV) and infrared (IR) represent 9% and 48% of the incoming solar radiation on Earth's surface. Harvesting these parts of the spectrum individually or collectively while transmitting the visible range is an effective way to achieve very high levels of transparency with colour neutrality. The theoretical PCE limit for a PV device optimally harvesting UV and IR is 21%, [4] which is comparable to the high-end of

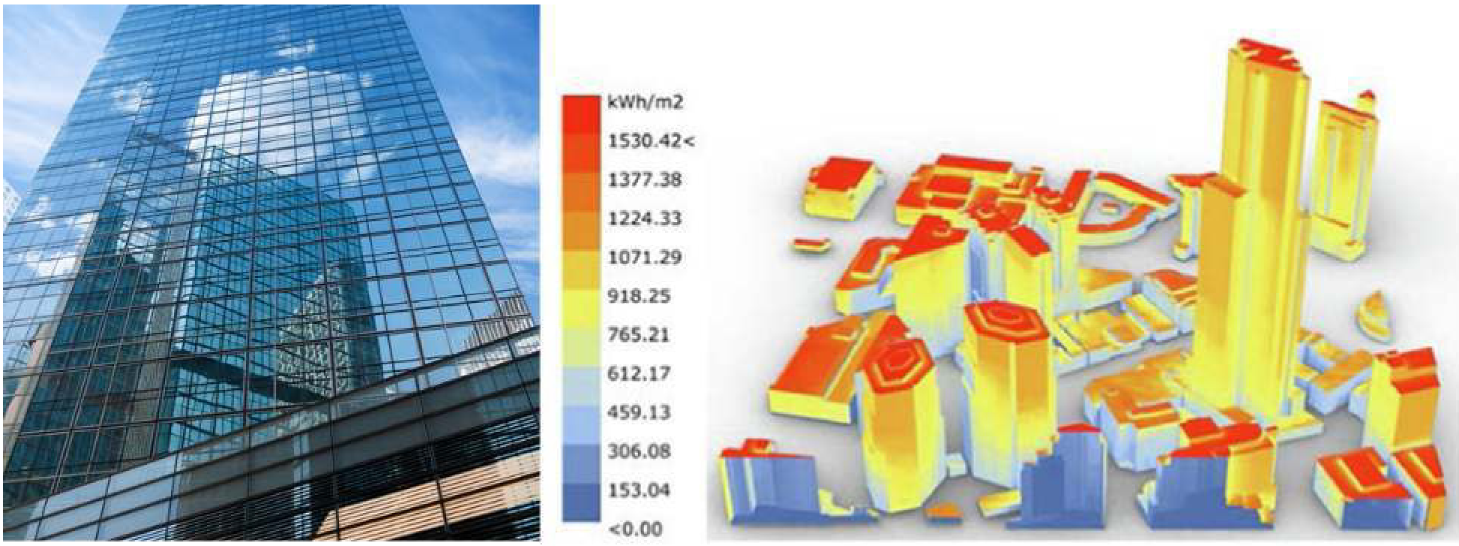


Figure 1: *Typical modern glazed building (chuyuss/shutterstock.com). (right) Annual solar radiation of a portion of the Melbourne CBD (reprinted from ref 3.)*

standard commercial rooftop panels. Luminescent Solar Concentrators (LSC) are widely used to achieve such spectral selectivity. LSCs harness fluorescent materials, such as quantum dots [5] and nanorods, [6] that are designed to absorb UV/IR while maximizing visible transmission. Light emission from these materials is guided to conventional solar cells embedded in a surrounding frame. This approach enables a high level of visible transparency and optical clarity. However, the PCE for current devices remains low, being in the range of a few percent, which entails power densities in the 10s of W/m². Several companies have already commercialised this technology.

Figure 2: *(top) Luminescent Solar Concentrator working principle. (bottom) A commercially available window (ClearVuepv.com).*

Semi-Transparent Solar Cells

Semi-transparent solar cells are devices that are engineered for incomplete absorption across the visible spectrum. This is achieved by reducing the thickness of the light absorber layer, which for strong absorbers is typically less than 200 nm.

In addition, the current-collecting electrodes in these devices are typically transparent conductors to enable efficient light transmission. Amorphous silicon PV technologies were the first to enter these markets, [7] but their low efficiencies of a few percent at reasonable light transparency levels have been met with limited commercial uptake. In response, a surge in research and development into alternative materials, such as organic molecules [8] and hybrid perovskites, [9] that can enable transparent PV with high efficiencies and colour-tunability has occurred in recent years. These efforts have led to lab-scale devices with PCEs above 12% and transparency levels above 30%.[10], [11] Today, such organic PVs are commercially available (though not as efficient), while hybrid perovskites derivatives are expected to follow in the next several years with great promise due to their higher PCEs.

Semi-Opaque Solar Cells

A straightforward approach to achieving transparency in PV is to partially cover a surface with opaque PV, thus allowing for light transmission through the exposed areas. Companies in the Building Integrated Photovoltaics (BIPV) space offer this solution by simply spacing out conventional silicon modules. The advantage with this approach is that the level of transparency is readily controlled and is proportional to the PCE (e.g., 200 W/m² modules with 50% coverage should generate 100 W/m²), while also maintaining color-neutral appearance.

These large scale semi-opaque geometries do block a significant portion of the view and therefore their implementation can result in losses to aesthetics and optical clarity.

An emerging path to resolve this issue is by minimizing the exposed areas to below the human eye resolution, which results in a tinted-glass appearance. A recent study has introduced micro-holes in crystalline-silicon solar cells, which induces neutral-color transmission and high PCE for a given transparency level.[12] The challenge with this approach is the scalable fabrication of micron-scale holes that do not compromise the efficiency of the device while enabling optical clarity to be maintained.

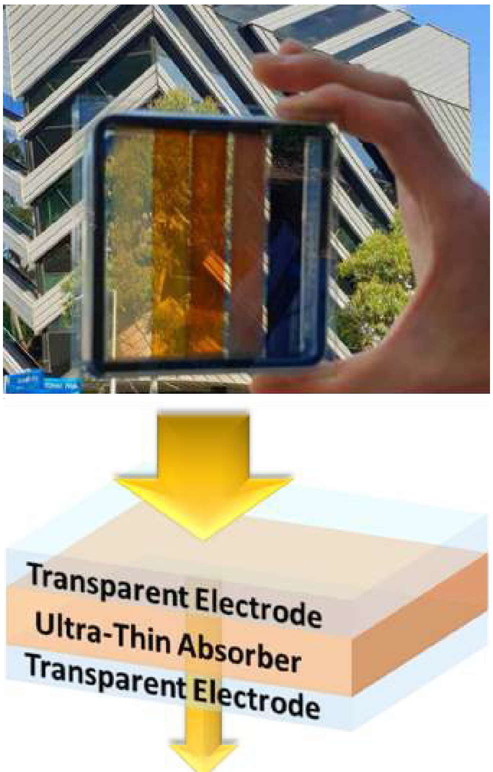


Figure 3: *((top) Semi-Transparent perovskite solar cells with varying colours16. (bottom) Device architecture.*

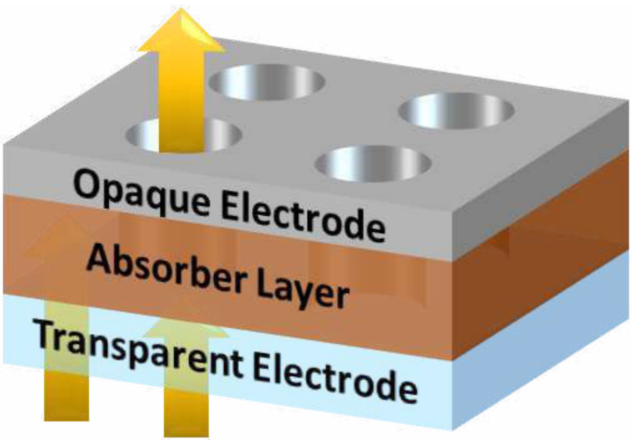


Figure 4:*(top) Semi-Opaque solar cells, as implemented today (dmitro2009/shutterstock.com). (bottom) Micro-hole device architecture.*

Outlook

Solar windows are a technology at its infancy. Within this class of PV, there are several key device architectures, each with different attributes that can enable differentiation in their prospective applications. The broader benefits of such technologies go beyond power generation as they contribute to improved thermal insulation, expanding the architectural design space and by controlling light levels within buildings. Moreover, smart solar windows with dynamic transparency may one day provide further functionality.[13] Importantly, the need for transparent PV goes beyond the urban construction market, with promising applications in areas such as agriculture and self-powered vehicles. While progress in scalability, stability and cost reductions are still necessary to realise commercial success of such technologies, [14], [15] with all the opportunities at hand, this is an area that is expected to exhibit significant growth.

References page 54, 55

Solar and wind investment jumps 50 per cent in 2022

Australian businesses and households made massive investments in renewable energy in 2022, according to recent data from the Clean Energy Regulator (CER). Read more

Going small and thin for better hydrogen storage

A collaboration including scientists from Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories, the Indian Institute of Technology Gandhinagar and Lawrence Berkeley National Laboratory has created 3-4 nanometer ultrathin nanosheets of a metal hydride that increase hydrogen storage capacity. The research appears in the journal Small.

There is a need for sustainable energy storage technologies that can address the intermittent nature of renewable energy resources. Hydrogen-based technologies are promising long-term solutions that reduce greenhouse gas emissions. Hydrogen has the highest energy density of any fuel and is considered a viable solution for ground transportation, aircraft and marine vessels. However, hydrocarbon fuel sources outperform compressed hydrogen gas in terms of volumetric energy density, motivating the development of alternative, higher-density materials-based storage methods.

Complex metal hydrides are a class of hydrogen storage materials that while having high absolute storage capacity, can require extreme pressures and temperatures to achieve that capacity. The team tackled this challenge by nano-sizing, which increases the surface area to react with hydrogen and decreases the required depth of hydrogenation. Previous studies have analyzed nanoscale magnesium diboride (MgB2), including work by LLNL, however, the material in that study was not as thin and wound up clustering together.

The material created in this most recent collaboration came from solvent-free mechanical exfoliation in zirconia, yielding material that is only 11-12 atomic layers thick and can hydrogenate to about 50 times the capacity of the bulk material. This 50-fold increase in the hydrogenation neatly corresponds to a 50-fold increase in the surface to volume ratio, suggesting that both the bulk and nanosheet material hydrogenate approximately the first two layers, a universal behavior independent of particle size. For two layers on either side of the 11-12-layer nanomaterial, this represents a third of the maximum hydrogen capacity of MgB2.

MgB2 consists of alternating magnesium and boron layers for which charge transfer from the magnesium layer to the boron layer drives the boron layer stability. LLNL calculations reveal that the incomplete Mg coverage on the surface of the material energetically favors a surface structure with islands of complete magnesium coverage and other areas of less stable disordered surface boron layers. Building from previous work on the disordering of surface boron layers, calculations show how magnesium coverage on MgB2 evolves as it hydrogenates.

“These results show how a reactive MgB2 surface with exposed boron may become more stable as it hydrogenates because the magnesium coverage increases,” said LLNL physicist and author Keith Ray. “By this mechanism the hydrogenation slows and halts for moderate hydrogenation conditions.

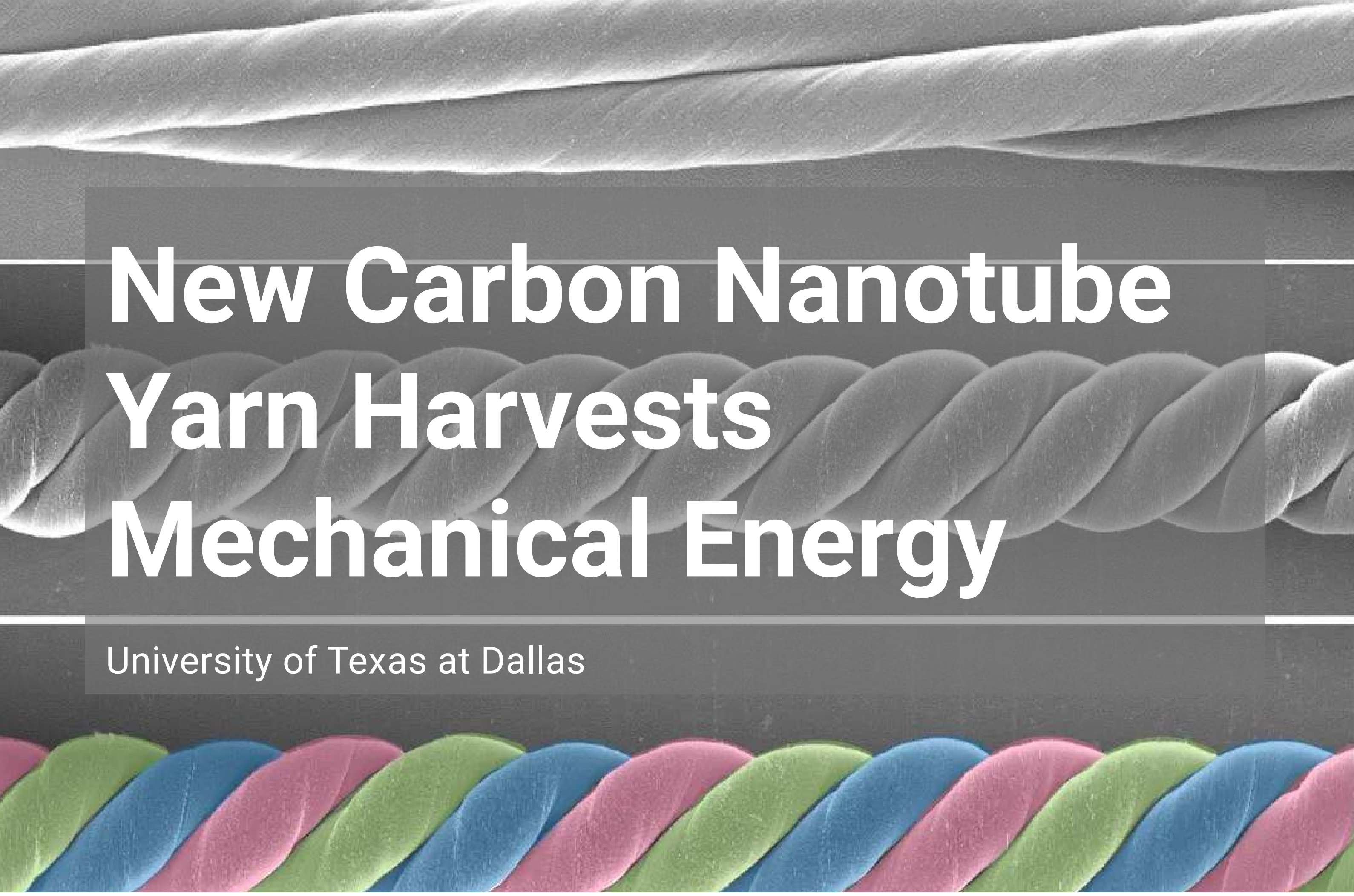
“Further nano-sizing or a novel chemical modification to delay or disrupt the increase in surface magnesium may further increase MgB2 performance as a hydrogen storage material,” he added.

Other LLNL authors include Maxwell Marple, Sichi Li and Brandon Wood.

The work is funded by the Hydrogen Storage Materials Advanced Research Consortium (HyMARC) in the Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen & Fuel Cell Technologies Office.

Written by Anne M Stark (LLNL)
Image by Liam Krauss (LLNL).

Hydrogen Storage in Partially Exfoliated Magnesium Diboride Multilayers
small, Volume19, Issue 6 February 8, 2023
https://doi.org/10.1002/smll.202205487



New Carbon Nanotube Yarn Harvests Mechanical Energy

University of Texas at Dallas

Nanotechnology researchers at The University of Texas at Dallas have made novel carbon nanotube yarns that convert mechanical movement into electricity more effectively than other material-based energy harvesters.

In a study published Jan. 26 in Nature Energy, UT Dallas researchers and their collaborators describe improvements to high-tech yarns they invented called “twistrons,” which generate electricity when stretched or twisted. Their new version is constructed much like traditional wool or cotton yarns.

Twistrons sewn into textiles can sense and harvest human motion; when deployed in salt water, twistrons can harvest energy from the movement of ocean waves; and twistrons can even charge supercapacitors.

First described by UTD researchers in a study published in 2017 in the journal Science, twistrons are constructed from carbon nanotubes (CNTs), which are hollow cylinders of carbon 10,000 times smaller in diameter than a human hair. To make twistrons, the nanotubes are twist-spun into high-strength, lightweight fibers, or yarns, into which electrolytes can also be incorporated.

Previous versions of twistrons were highly elastic, which the researchers accomplished by introducing so much twist that the yarns coil like an overtwisted rubber band. Electricity is generated by the coiled yarns by repeatedly stretching and releasing them, or by twisting and untwisting them.

In the new study, the research team did not twist the fibers to the point of coiling. Instead, they intertwined three individual strands of spun carbon nanotube fibers to make a single yarn, similar to the way conventional yarns used in textiles are constructed — but with a different twist.

“Plied yarns used in textiles typically are made with individual strands that are twisted in one direction and then are plied together in the opposite direction to make the final yarn. This heterochiral construction provides stability against untwisting,” said Dr. Ray Baughman, director of the Alan G. MacDiarmid NanoTech Institute at UT Dallas and the corresponding author of the study.

"In contrast, our highest-performance carbon-nanotube-plied twistrons have the same-handedness of twist and plying — they are homochiral rather than heterochiral,” said Baughman, the Robert A. Welch Distinguished Chair in Chemistry in the School of Natural Sciences and Mathematics.

In experiments with the plied CNT yarns, the researchers demonstrated an energy conversion efficiency of 17.4% for tensile (stretching) energy harvesting and 22.4% for torsional (twisting) energy harvesting. Previous versions of their coiled twistrons reached a peak energy conversion efficiency of 7.6% for both tensile and torsional energy harvesting.

“These twistrons have a higher power output per harvester weight over a wide frequency range — between 2 hertz and 120 hertz — than previously reported for any non-twistron, material-based mechanical energy harvester,” Baughman said.

“Our materials do something very unusual. When you stretch them, instead of becoming less dense, they become more dense. This densification pushes the carbon nanotubes closer together and contributes to their energy-harvesting ability.”

Dr. Ray Baughman, the Robert A. Welch Distinguished Chair in Chemistry in the School of Natural Sciences and Mathematics

Baughman said the improved performance of the plied twistrons results from the lateral compression of the yarn upon stretching or twisting. This process brings the plies in contact with one another in a way that affects the electrical properties of the yarn.

“Our materials do something very unusual,” Baughman said. “When you stretch them, instead of becoming less dense, they become more dense. This densification pushes the carbon nanotubes closer together and contributes to their energy-harvesting ability. We have a large team of theorists and experimentalists trying to understand more completely why we get such good results.”

The researchers found that constructing the yarn from three plies provided the optimal performance.

The team conducted several proof-of-concept experiments using three-ply twistrons. In one demonstration they simulated the generation of electricity from ocean waves by attaching a three-ply twistron between a balloon and the bottom of an aquarium filled with salt water. They also arranged multiple plied twistrons in an array weighing only 3.2 milligrams and repeatedly stretched them to charge a supercapacitor, which then had enough energy to power five small light-emitting diodes, a digital watch and a digital humidity/temperature sensor.

“Our materials do something very unusual. When you stretch them, instead of becoming less dense, they become more dense."
Dr. Ray Baughman

The team also sewed the CNT yarns into a cotton fabric patch that was then wrapped around a person’s elbow. Electrical signals were generated as the person repeatedly bent their elbow, demonstrating the potential use of the fibers for sensing and harvesting human motion.

The researchers have applied for a patent based on the technology.

Other NanoTech Institute researchers involved in the work are co-lead authors Dr. Mengmeng Zhang, research associate, and Dr. Wenting Cai, former visiting scientist; Zhong Wang PhD’21, research associate; Dr. Shaoli Fang, associate research professor; Dr. Ali E. Aliev, research professor; Dr. Anvar Zakhidov, deputy director of the institute and professor of physics; and Dr. Jiyoung Oh, research scientist. Other contributors from UTD were Runyu Zhang, mechanical engineering doctoral student, and Dr. Hongbing Lu, professor of mechanical engineering and holder of the Louis Beecherl Jr. Chair.

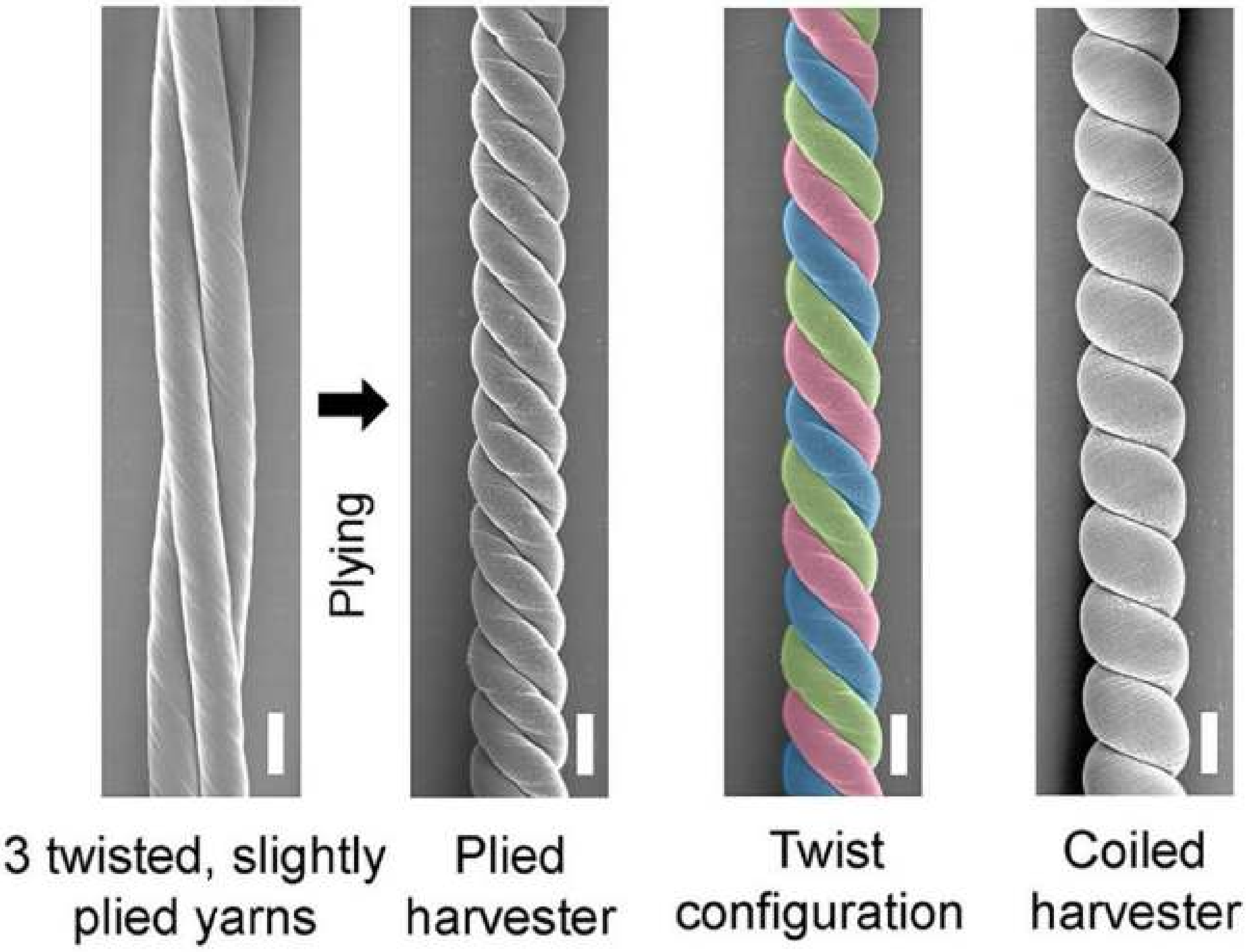
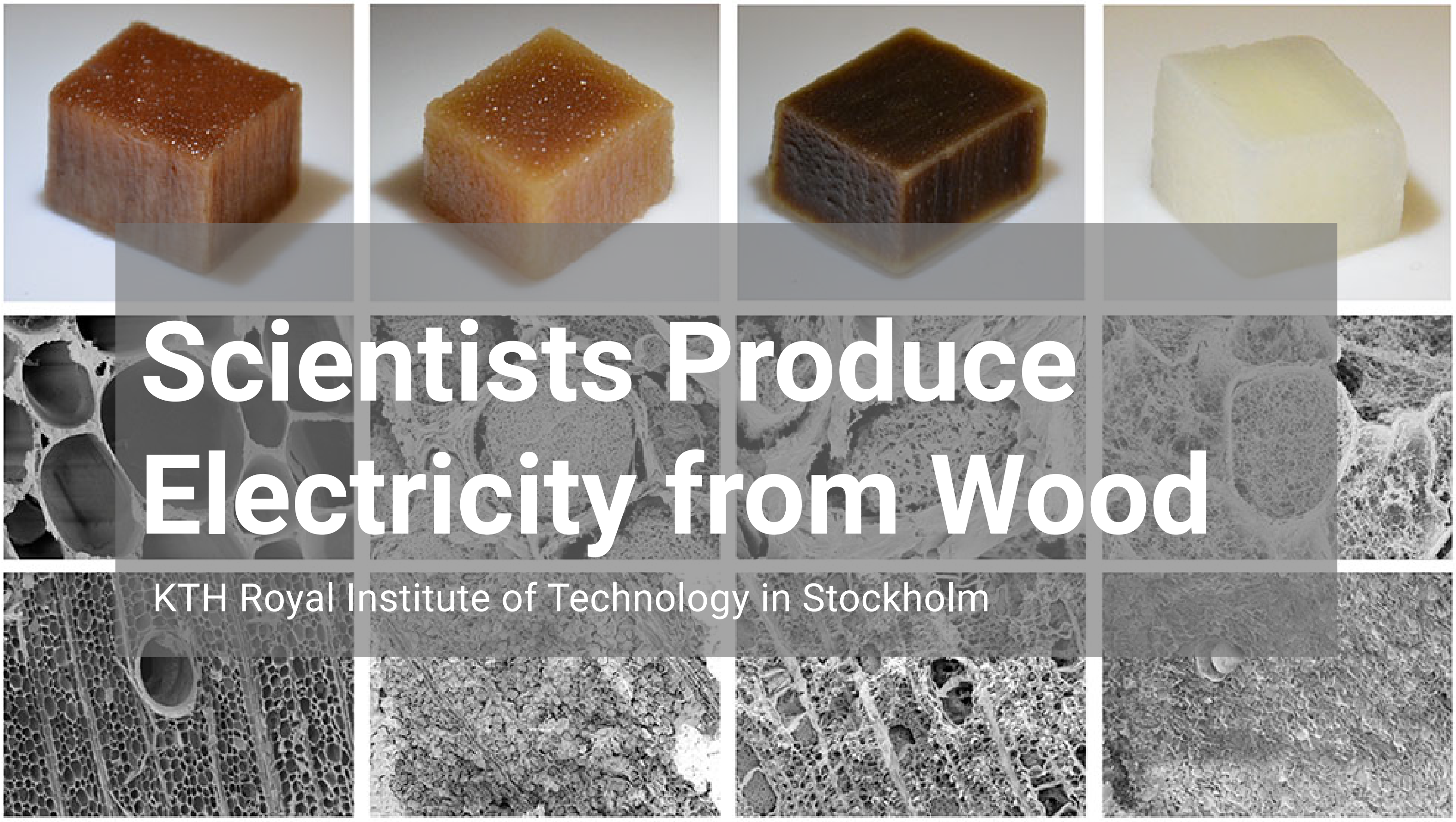


Figure 1: *Twistrons, made from spun carbon nanotubes (CNTs), convert mechanical movement into electricity. Scanning electron microscope images show how UT Dallas researchers made a new kind of twistron by intertwining three individual strands of spun carbon nanotube fibers to make a single yarn, similar to the way conventional yarns used in textiles are constructed. A previous version of a harvester (right) was made by coiling the CNT fibers. The scale bars indicate 100 micrometers.*

Researchers from Xi'an Jiaotong University and Wuhan University in China, Hanyang University in South Korea, and Lintec of America Inc.'s Nano-Science & Technology Center also contributed.

Funding sources of the research include the U.S. Navy, the Air Force Office of Scientific Research, The Welch Foundation, the National Science Foundation and the Department of Energy.

Media Contact: Amanda Siegfried, UT Dallas, 972-883-4335, amanda.siegfried@utdallas.edu, or the Office of Media Relations, UT Dallas, (972) 883-2155, newscenter@utdallas.edu.



Scientists Produce Electricity from Wood

KTH Royal Institute of Technology in Stockholm

At a time when energy is an issue affecting many millions of people worldwide, scientists at KTH have managed to harvest electricity by passing water through refined wood. Their work has recently been published in the journal Advanced Functional Materials.

What happens if wood is put into water, and the water then evaporates like in nature? Transpiration – this process of water movement through a plant is constantly occurring in nature. The process also produces small amounts of electricity, known as bioelectricity.

WOODOO augmented wood

Nanoengineering improves the wood’s properties

Researchers at KTH have focused in on this. In order to increase the amount of electricity that can be harvested, the scientists have used nanoengineering to improve the properties of the wood. This is because electricity generation in wood is influenced by several factors such as area, porosity (density), surface charge,how readily water can pass through the material, and the water solution itself.

"We have compared the porous structure in regular wood with the material we have improved with regard to surface, porosity, surface charge and water transportation. We have measured electricity generation that’s ten times higher than natural wood," says Yuanyuan Li, Associate Professor at the Division of Biocomposites at KTH.

Ten times higher

She adds that further tuning the pH difference between wood and water, due to an ion concentration gradient, achieves a potential of up to one volt and a remarkable power output of 1.35 microwatts per square centimetre.

"At the moment we can run small devices such as an LED lamp or a calculator. If we wanted to power a laptop, we would need about one square metre of wood about one centimetre thick, and about two litres of water. For a normal household we'd need far more than that, so more research is needed."

Li says that to date, the wood has managed to deliver high voltage for about 2–3 hours, before it starts waning. According to the researchers, so far the wood has managed ten cycles with water, without a decline in the material's performance.

"The great advantage of this technology is that the wood can readily be used for other purposes once it's depleted as an energy source, such as transparent paper, wood-based foam and different biocomposites."

Reference:

Advancing Hydrovoltaic Energy Harvesting from Wood through Cell Wall Nanoengineering
Jonas Garemark, Farsa Ram, Lianlian Liu, Ioanna Sapouna, Maria F. Cortes Ruiz, Per Tomas Larsson, Yuanyuan Li
https://onlinelibrary.wiley.com/doi/10.1002/adfm.202208933

Image: On the far left, natural wood is seen. The three pieces of wood on the right have undergone different types of treatment that give a higher surface area and smaller pores, which provide rapid water transport through the material.
@ Jonas Garemark

Adelaide To Host 2024 International Renewable Energy Conference

REN21, the Australian Government, the South Australian Government and the Clean Energy Council today announced Adelaide, South Australia, has been selected as the host city for the Australia 2024 International Renewable Energy Conference (AUSIREC).
[Read more](#)

Engineered Nanomaterials could replace Critical Minerals in Clean Energy Technologies

NWA

Let us begin by defining, in the context of this article, what critical minerals are. First they are minerals, and they are rare. They are found in limited quantity in nature, in the Earth's crust, or perhaps they are technically abundant but diffused over large areas, making difficult to find hotspots which are economically viable to extract. Critical minerals are in limited supply. Their extraction is difficult and comes at a high financial cost. As waste chemicals needed for their extraction seep into the ground, infiltrate water and generate toxic dust which pollutes the air, critical minerals also come at a high environmental cost.

As the world is making strides towards clean energy technologies, this paradoxically increases the demand for critical minerals, as many of them are key components of clean energy production, transmission and storage (Figure 1).

Rare Earth Elements (REEs) such as dysprosium, terbium, europium, neodymium and yttrium are used as key components of the permanent magnets for wind turbines and electric vehicles, or as phosphors in energy efficient lighting; silicon, tellurium and indium make up important parts of solar photovoltaic panels; platinum and palladium are used for fuel cells; and of course lithium for batteries powering cell phones, laptops and electric vehicles.

Critical minerals are ubiquitous in clean energy systems, despite their uninspiring ecological footprint. But their importance also fuels some fundamental doubts about whether their limited supply could ever

> ***Today's mineral supply and investment plans fall short of what is needed to transform the energy sector, raising the risk of delayed or more expensive energy transitions.*** **IEA**

feed the growing, looming future demand. In addition, their limited accessibility can be further exacerbated by supply chain disruptions such as political restrictions or environmental regulations. Furthermore, as the use of critical minerals typically represent small quantities across a large volume of widely diffused components, their recycling is a difficult and costly endeavor.

One potential pathway to solving some of these problems would be to find alternative materials – or perhaps even better, to create them. Several critical minerals may actually be substituted by engineered nanomaterials based on one of the most abundant and eco-friendly elements: carbon. More specifically, graphene, nanotubes and fullerenes. The fact that carbon nanomaterials (CNMs) have properties similar to metals is very promising – and so have been the results of several such experiments.

> ***In the transition to clean energy, critical minerals bring new challenges to energy security.***
> **IEA**

A shift away from the use of critical minerals to CNMs is already taking place. The high conductivity and mechanical strength of graphene and carbon nanotubes make them ideal for use in photovoltaics and batteries. Chromium, cobalt, gallium and indium have already been successfully substituted in some of their main applications by CNMs. We will undoubtedly see much more innovation in this area in the coming years, which will help reduce our dependency on critical minerals.

Reference page 52

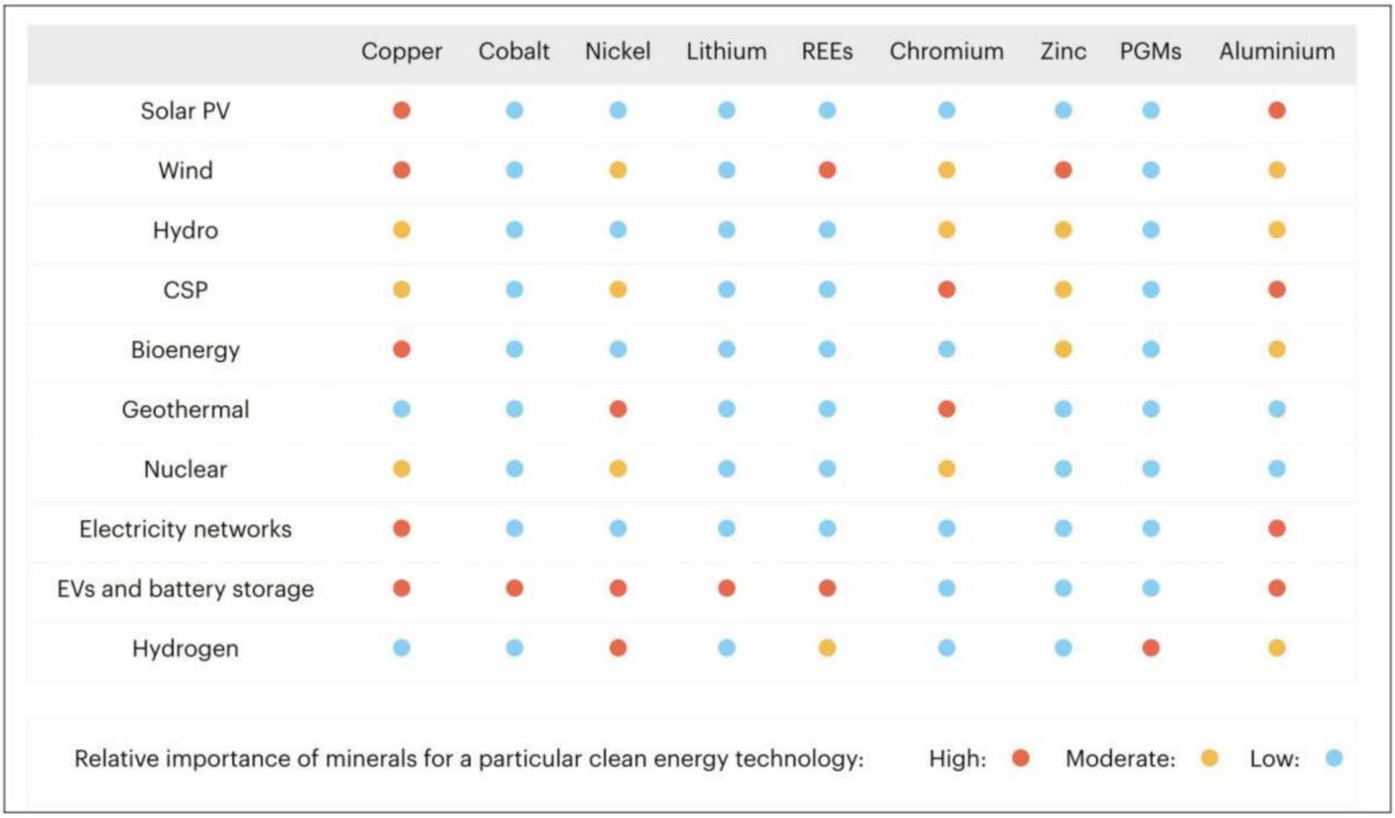


Figure 1: *Critical minerals required for clean energy technologies. Source: IEA. 2021, p45.*

LOOP: producing hydrogen and graphene through the decarbonisation of methane

LOOP is a decarbonisation device designed to accelerate the world's transition to net zero. The process has two products: hydrogen, a clean energy source, and net zero graphene, a material reshaping the world we live in.

LOOP seamlessly docks with existing infrastructure to strip carbon from methane, helping businesses to decarbonise instantly. Upon installing LOOP, the average business could **reduce the CO2** potential of their natural gas by **up to 40%** instantly by replacing it with hydrogen, a more sustainable fuel.

This device can be deployed to any site that produces methane (such as a wastewater treatment plant) or uses natural gas.

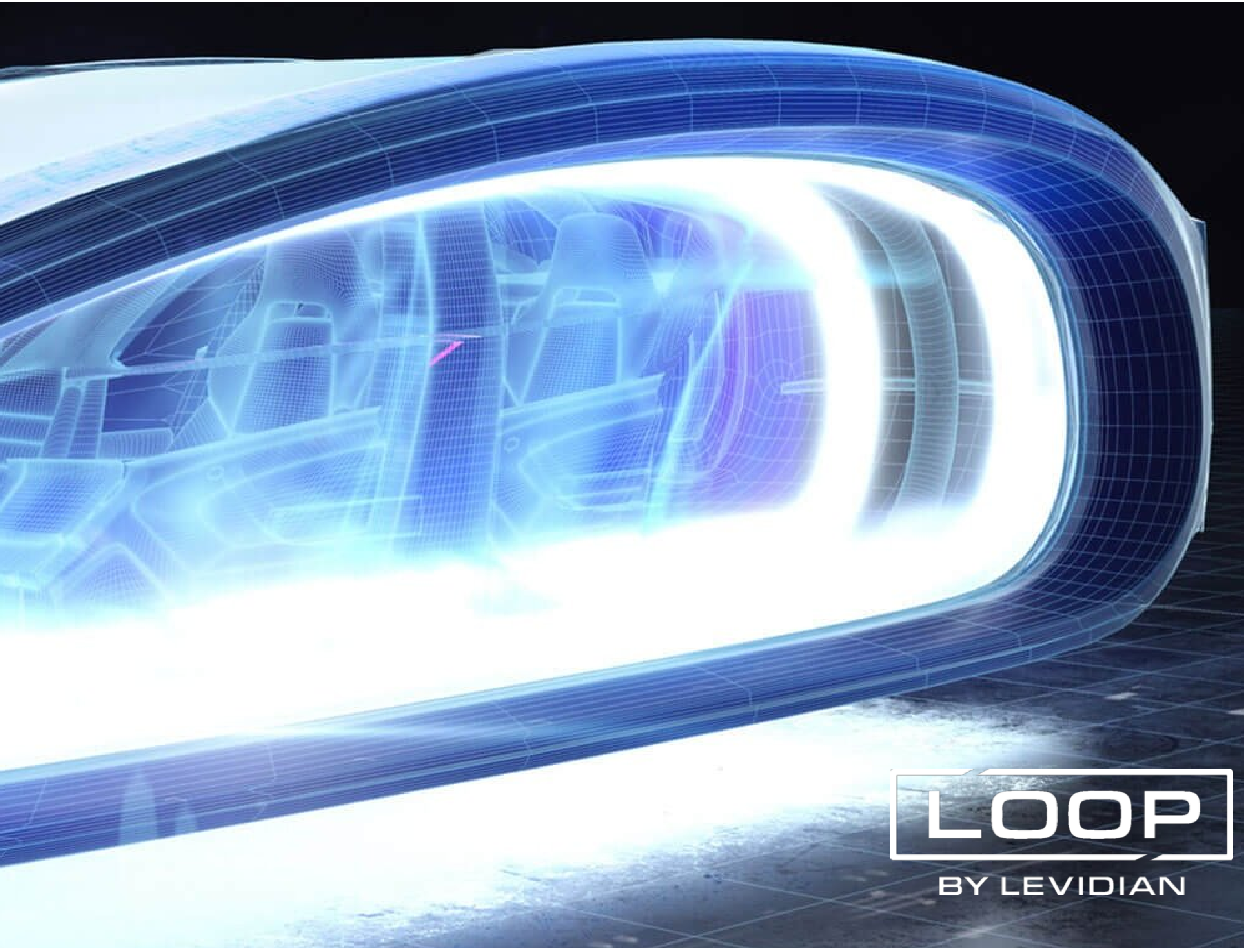
Putting Waste Methane to Good Use
A quarter of global warming is caused by methane.

Encouragingly there are a growing number of options for capturing methane and turning it into useful products.

In their whitepaper they explore the three main methane cracking technologies; SMR, Pyrolysis and Microwave Plasma.

In a world where mitigating climate change looks hugely costly – and the impact of doing nothing even worse – the opportunities presented by methane cracking are a rare bit of good news.

Download the White Paper



Where can LOOP be deployed?

Process heat users & gas-fired power generators: LOOP strips carbon from natural gas to decarbonise your heat source by up to 40%. This deployment also provides a stream of graphene for use or re-sale.

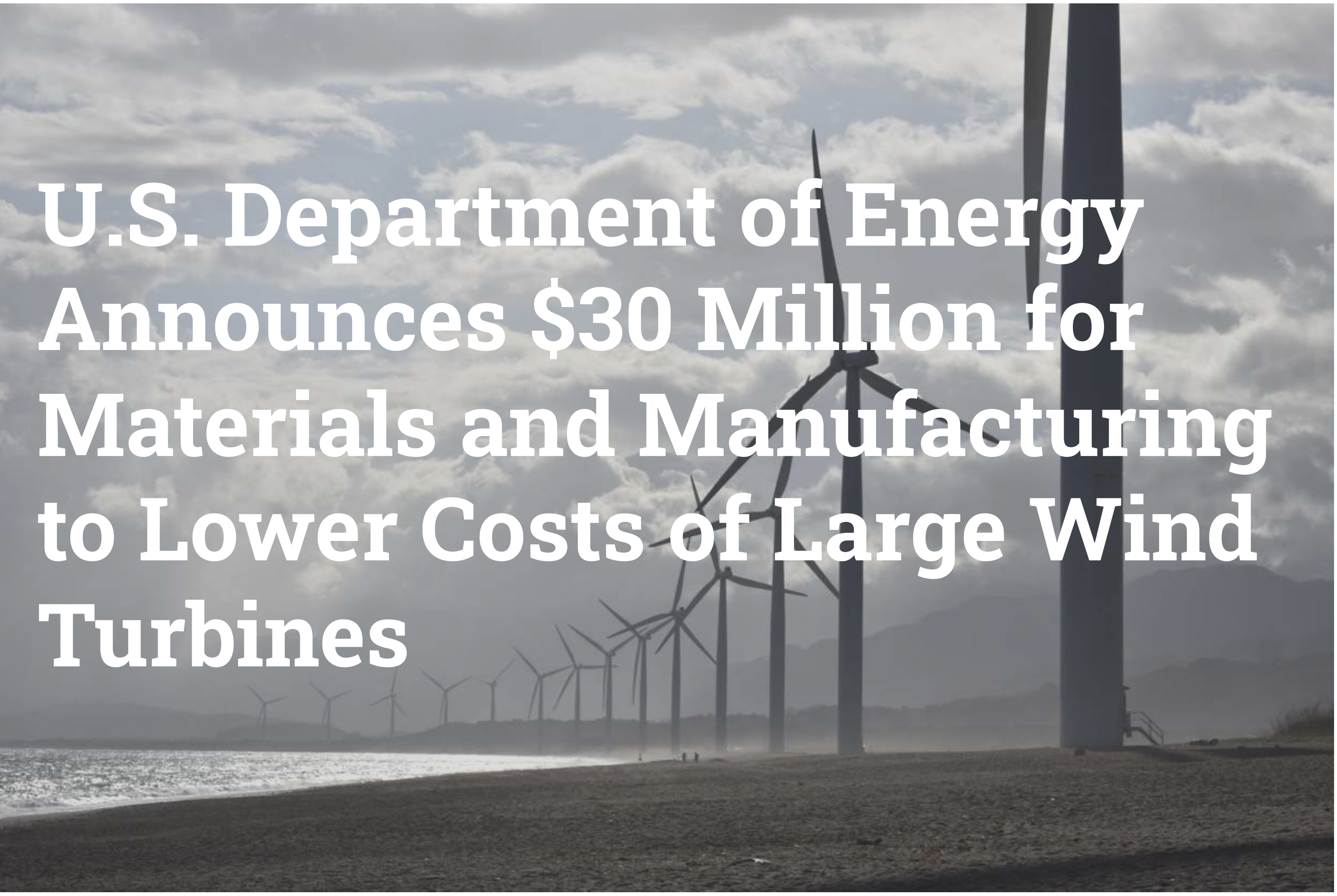
Pure hydrogen users & blended gas grids: An efficient way of increasing the hydrogen of the gas blend, this reduces the CO2 emissions associated with traditional combustion. Pure hydrogen can also be separated and used or stored.

Anaerobic digestion, waste gas, or flaring locations: Waste gas is used directly as an input to LOOP. Hydrogen can be compressed and removed or used on site, and the graphene can be collected for re-sale.

Graphene enhanced production manufacturers: Using a sustainable local methane source, graphene can be extracted and re-adopted on site – reducing the need for expensive transportation. The resulting hydrogen or hydrogen-methane blend can be compressed for use elsewhere or used to power process/heating on site.

LOOP is a tried and tested decarbonisation tool – Levidian has used the device for over ten years at their Cambridge site.

Founded in 2012, Levidian is a British climate tech business whose patented technology cracks methane into hydrogen and carbon, locking the carbon into **high-quality green graphene**.



U.S. Department of Energy Announces $30 Million for Materials and Manufacturing to Lower Costs of Large Wind Turbines

Funding Opportunity Seeks to Increase Cost Efficiency of Wind Power Generation Through R&D Projects for Lightweight Materials, Streamlined 3-D Printing Processes

WASHINGTON, D.C. — The U.S. Department of Energy (DOE) today announced a $30 million funding opportunity to advance the cost-effective domestic manufacturing of materials, including lightweight composites, that allow wind turbines to produce power more efficiently. Because wind energy is the largest source of renewable power in the United States and one of the most affordable sources of energy today, it is a critical tool for reducing our reliance on fossil energy, and next-generation technologies and manufacturing improvements will help bring down costs even more. The improved materials and manufacturing processes envisioned under this funding opportunity have the potential to reduce wind energy costs and expand the deployment of the nation's wind energy portfolio in support of President Biden's goals to reach 100% clean electricity by 2035 and a net-zero-emissions economy by 2050.

"The wind sector has proven to be a reliable source of clean power for homes and businesses in a variety of geographic areas," said U.S. Secretary of Energy Jennifer M. Granholm. "Investing in next-generation materials that will lower the financial barriers to widespread deployment supports President Biden's domestic manufacturing and clean energy goals."

Lightweight composite materials reduce emissions in a variety of ways, including by enabling more efficient wind power generation and lightening the weight of vehicles, making them more fuel efficient. Led by the Office of Energy Efficiency and Renewable Energy (EERE)'s Advanced Materials and Manufacturing Technologies Office (AMMTO), this funding opportunity seeks to improve the manufacturability and performance of composite materials associated with wind energy technologies. Specifically, this opportunity seeks to streamline the additive manufacturing (3-D printing) processes for rapid prototyping, tooling, fabrication, and testing of large wind blades. It also seeks to apply additive manufacturing with polymers, metals, ceramics, or composite systems to non-blade wind turbine components like those comprising drivetrains or floating offshore wind platforms.

Applicants for this funding opportunity are required to submit projects that focus on one of the following topic areas:

- **Large Wind Blade Additive Manufacturing** that builds on existing polymer-based additive manufacturing research that supports and advances more cost-effective large wind turbine blades. Polymer-based additive manufacturing generally allows for rapid prototyping, tooling, fabrication, and testing in support of novel designs and process configurations.

- **Additive Manufacturing of Non-Blade Wind Turbine Components** that can be improved through additive manufacturing and associated design and process integration.

- **Large Wind Blades: Advancing Manufacturing, Materials, and Sustainability** to address the remaining challenges to wind turbine manufacturing and build on previous work within the areas of automation, digitalization, wind blade sustainability, and modular blade construction and joining.

Projects funded through this initiative will also support priorities established in the recently announced Offshore Wind Supply Chain Road Map and interagency Floating Offshore Wind Shot.

The estimated period of performance for the award will be two to three years. Concept papers are due March 23, 2023, at 5 P.M. ET.

View the full funding opportunity.

Learn more about AMMTO and its work to advance energy-related materials and manufacturing technologies to increase domestic competitiveness and build a clean, decarbonized economy.

U.S. Department of Energy

SunHydrogen Unveils Larger Version of the World's First-Ever Nanoparticle-Based Green Hydrogen Generator

The system is designed to be economical at mass-manufacturing scale

SunHydrogen, the developer of a breakthrough technology to produce renewable hydrogen using sunlight and water, today published a photo of the largest version to date of its nanoparticle-based green hydrogen technology.

The image unveiled today shows a panel that houses multiple hydrogen generators and contains 16 times more hydrogen generator area than the Company's previous small-scale model. Multiple arrays of hydrogen generators bolster hydrogen production rates.

This prototype is currently the only self-contained nanoparticle-based hydrogen generation device of its kind that splits water molecules into high-purity green hydrogen and oxygen using the sun's energy.

SunHydrogen's nanoparticle technology directly uses the electrical charges created by sunlight to generate hydrogen when the sun is shining. However, this prototype was also designed to support 24-hour operation even when the sun is not shining by powering the catalyst and membrane integration assembly with renewable grid electricity from wind or hydropower sources.

The Company's previous small-scale model, publicized in December 2022, was designed to fit a single nanoparticle-based hydrogen generator for testing in a controlled environment.

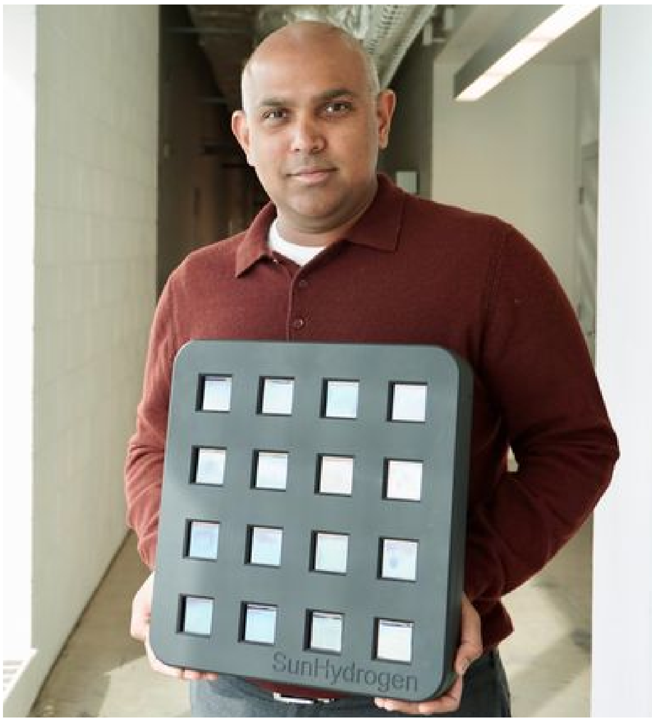
"This larger-scale panel moves us one step closer to producing commercial-scale hydrogen panels," said SunHydrogen's Chief Scientific Officer Dr. Syed Mubeen.

“Just like a solar panel is comprised of multiple cells, our hydrogen panel encases multiple hydrogen generators, as pictured. However, because we are growing our own nanoparticle semiconductor units using low-cost, abundant materials, we are not reliant on expensive solar cell materials and architecture. We believe that when our efficiency goals are met, this will prove to be one of – if not the most – economical green hydrogen solutions,” Dr. Mubeen concluded.

SunHydrogen’s Iowa scientific team is currently working to increase the hydrogen production rate per panel by increasing the hydrogen generator area to panel area ratio, as well as overall panel size. The Company is also working to improve overall solar-to-hydrogen efficiency through its agreement with the National Renewable Energy Laboratory (NREL), as well as with its industrial partner InRedox and the Singh Lab at the University of Michigan. In parallel, the Company is working to improve the overall stability of the hydrogen generators.

“I am extremely proud of our team and our industrial partners for meeting another milestone in the path to scaling up our technology, and I am grateful for our shareholders’ patience and support as we work to improve efficiency, overcome challenges, and bring our vision to fruition,” said SunHydrogen’s CEO Tim Young.

Note: A hydrogen generator refers to the entire unit structure composed of substrate, protective layer, photovoltaic layers, and oxidation/reduction catalyst, in which billions of nanoparticles split apart water at the molecular level. A hydrogen panel houses multiple arrays of such hydrogen generators.



“This larger-scale panel moves us one step closer to producing commercial-scale hydrogen panels,” said SunHydrogen’s Chief Scientific Officer Dr. Syed Mubeen, pictured here.

Future communications will continue to clarify this distinction between hydrogen generator and hydrogen panel.

About SunHydrogen, Inc.
SunHydrogen is developing breakthrough technologies to make, store and use green hydrogen in a market that Goldman Sachs estimates to be worth $12 trillion by 2050. The patented SunHydrogen Panel technology, currently in development, uses sunlight and any source of water to produce low-cost green hydrogen. Similar to solar panels that produce electricity, our SunHydrogen Panels will produce green hydrogen. Our vision is to become a major technology supplier in the new hydrogen economy. By developing, acquiring and partnering with other critical technologies, we intend to enable a future of emission-free vehicles, ships, data centers, aircrafts and more. To learn more about SunHydrogen, please visit www.SunHydrogen.com.

The Potential of Nanotec Production

NWA

Derived from renewable sources, biofuels offer a promising alternative to traditional fossil fuels. However, the production of biofuels typically faces several challenges such as high production costs and low yields. Nanotechnology has the potential to revolutionize the way biofuels are produced, by helping address these challenges and improving the efficiency and sustainability of biofuel production.

One such improvement is the enhancement of the biomass synthesis and conversion. Biomass conversion is a complex and energy-intensive process that involves the breakdown of complex organic molecules into simpler compounds that can be further processed into biofuels. Various nanomaterials, including metal oxide and magnetic nanoparticles, carbon nanotubes and nanofibers, nanosheets and zeolites, possess unique properties such as high surface area to volume ratio – and special attributes such as a significant extent of crystallinity, catalytic activity and reactivity, adsorption capacity, and stability – which make them ideal for use as nano-catalysts in biofuel production. Furthermore nanoparticles can be and are used in the pretreatment process to enhance the digestibility of substrates.

For example, nanotechnology plays an important role in biogas and methane production as it has a bio-stimulating effect on the methanogenic phase. Nano zero valence iron (NZVI) has been shown to affect the anaerobic digestion (AD) by increasing the production of biogas and methane. Moreover, NZVI stimulates the methanogenesis in the process of AD while inhibiting dichlorination.

Microbial enzymes such as lipase from Pseudomonas cepacia immobilized on the surface of

chnology in Biofuel

nanoparticles enhance the production of biofuel due to an enhanced transesterification reaction. Fictionalization of the nanoparticle process also increases the production of biodiesel. Nanoconjugates have also been shown to increase the production of biodiesel.

The most common method used for production of biohydrogen involves dark fermentation, during which by-products are formed which inhibit the hydrogen production. Several metal (Ag, Au, Cu, Fe, Ni) and metal oxide nanoparticles as well as nanocomposites (for example silica with iron oxide) have been successfully shown to reduce this effect via higher catalytic activity, thus significantly enhancing the hydrogen production. Moreover these nanocomposites provide additional advantages such as stability at high temperatures and low toxicity.

Silica nanoparticles are often deposited on the surface of nanoparticles for the immobilization of lignocellulolytic enzymes such as cellulase, and have also been shown to increase catalytic activity in the synchronous saccharification step for bioethanol synthesis using Trichodermaviride cellulose.

Nanoparticles in heterogeneous catalysts have emerged in the production of biofuel as an advancement on homogenous catalysts as they do not need too much water. Their separation is easy, and one can obtain contaminant-free products, which are normally non-corrosive, eco-friendly, and with high selectivity and long lifetimes.

On a different register, in terms of the feedstock itself which is being used, while it was a significant improvement to go from edible feedstock (vegetable oils such as

sunflower or palm, soybeans, sugarcane and corn) to non-edible (waste vegetable oil, jatropha, wood chips and agricultural residue) – biofuel production still remained costly. However the latest generation of feedstock consists mainly of lignocellulosic biomass, as well as algal biomass, which is oil-rich, carbon-neutral, and can grow rapidly. When combining more efficient nano-catalysts with these latest types of feedstock, it is now possible to solve the yield issue while reducing the energy required for the process, making the production faster and much more cost-effective.

In addition to increasing microalgae conversion and biofuel yield, nanotechnology also proposes applications which can enhance microalgae cell density at the cultivation stage, thus generating higher biomass yield at the harvesting stage.

Microalgae cultivation as feedstock for biofuel production also provides the following benefits:

- does not clash with human or animal food chains
- can grow in freshwater, saline water or wastewater
- requires low water levels, and can grow over the whole year
- short harvesting life cycle
- uses up carbon dioxide for photosynthesis
- develops sustainable oxygen generation

Several biofuels – biohydrogen, biodiesel, bioethanol, biomethanol, biogas, bioacetone, biobutanol, biochar and others – can now be more efficiently produced with the application of nanotechnology, but they still have several properties which need to be optimized for their successful use as fuels – such as their energy content, stability, and compatibility with existing engines and infrastructure. Nanotechnology can also be used to modify the structure and composition of biofuels, improving their properties and making them more suitable for use as fuels.

Nanoadditives can increase the efficiency of biofuels enabling them to compete with available natural fuels by: decreasing the ignition delay; achieving a complete and cleaner combustion; providing outstanding thermal efficiency; providing a higher yield at a lower cost.

From cultivation to conversion to combustion, nanotechnology can help throughout all stages of biofuel production. Efficiency will continue to improve, while remaining challenges are tackled – such as optimizing the integration of these materials into existing processes, and scaling up these processes to industrial scales.

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Your Guide to Australia's Energy Transition
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European Commission Proposes Regulation for Renewable Hydrogen Definition

Today, the Commission has proposed detailed rules to define what constitutes renewable hydrogen in the EU, with the adoption of two Delegated Acts required under the Renewable Energy Directive. These Acts are part of a broad EU regulatory framework for hydrogen which includes energy infrastructure investments and state aid rules, and legislative targets for renewable hydrogen for the industry and transport sectors. They will ensure that all renewable fuels of non-biological origin (also known as RFNBOs) are produced from renewable electricity. The two Acts are inter-related and both necessary for the fuels to be counted towards Member States' renewable energy target. They will provide regulatory certainty to investors as the EU aims to reach 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imported renewable hydrogen in line with the REPowerEU Plan.

More renewables, less emissions

The first Delegated Act defines under which conditions hydrogen, hydrogen-based fuels or other energy carriers can be considered as an RFNBO. The Act clarifies the principle of “additionality” for hydrogen set out in the EU's Renewable Energy Directive. Electrolysers to produce hydrogen will have to be connected to new renewable electricity production. This principle aims to ensure that the generation of renewable hydrogen incentivises an increase in the volume of renewable energy available to the grid compared to what exists already. In this way, hydrogen production will be supporting decarbonisation and complementing electrification efforts, while avoiding pressure on power generation.

While initial electricity demand for hydrogen production will be negligible, it will increase towards 2030 with the mass rollout of large-scale electrolysers. The Commission estimates that around 500 TWh of renewable electricity is needed to meet the 2030 ambition in REPowerEU of producing 10 million tonnes of RFNBOs. The 10Mt ambition in 2030 corresponds to 14% of total EU electricity consumption. This ambition is reflected in the Commission proposal to increase the 2030 target for renewables to 45%.

The Delegated Act sets out different ways in which producers can demonstrate that the renewable electricity used for hydrogen production complies with additionality rules. It further introduces criteria aimed to ensure that renewable hydrogen is only produced when and where sufficient renewable energy is available (known as temporal and geographic correlation).

To take into account existing investment commitments and allow the sector to adapt to the new framework, the rules will be phased in gradually, and designed to become more stringent over time. Specifically, the rules foresee a transition phase of the requirements on "additionality" for hydrogen projects that will start operating before 1 January 2028.This transition period corresponds to the period when electrolysers will be scaled up and come onto the market. Furthermore, hydrogen producers will be able to match their hydrogen production with their contracted renewables on a monthly basis until the 1 January 2030. However, Member States will have the option of introducing stricter rules about temporal correlation as of 1 July 2027.

The requirements for the production of renewable hydrogen will apply to both domestic producers as well as producers from third countries that want to export renewable hydrogen to the EU to count towards the EU renewables targets. A certification scheme relying on voluntary schemes will ensure that producers, whether in the EU or in third countries, can demonstrate in a simple and easy way their compliance with the EU framework and trade renewable hydrogen within the Single Market.

The second Delegated Act provides a methodology for calculating life-cycle greenhouse gas emissions for RFNBOs. The methodology takes into account greenhouse gas emissions across the full lifecycle of the fuels, including upstream emissions, emissions associated with taking electricity from the grid, from processing, and those associated with transporting these fuels to the end-consumer. The methodology also clarifies how to calculate the greenhouse gas emissions of renewable hydrogen or its derivatives in case it is co-produced in a facility that produces fossil-based fuels.

Following today's adoption, the Acts will now be transmitted to the European Parliament and the Council, which have 2 months to scrutinise them and to either accept or reject the proposals. At their request, the scrutiny period can be extended by 2 months. There is no possibility for the Parliament or Council to amend the proposals.

Background

In 2020, the Commission adopted a Hydrogen Strategy setting out a vision for the creation of a European hydrogen ecosystem from research and innovation to production and infrastructure, and development of international standards and markets. Hydrogen is expected to play a major role in the decarbonisation of industry and heavy-duty transport in Europe and globally. As part of the ‘Fit for 55' package, the Commission has introduced several incentives for its uptake, including mandatory targets for the industry and transport sectors.

"Renewable hydrogen is a crucial component of our strategy for a cost-effective clean energy transition and to get rid of Russian fossil fuels in some industrial processes. Clear rules and a reliable certification system are key for this emerging market to develop and establish itself in Europe. These delegated acts provide much-needed legal certainty to investors, and will further boost the EU's industrial leadership in this green sector."

Kadri Simson, Commissioner for Energy - 13/02/2023

Hydrogen is also a key pillar of the REPowerEU Plan to get rid of Russian fossil fuels. The Commission has outlined a ‘Hydrogen Accelerator' concept to scale up the deployment of renewable hydrogen. In particular, the REPowerEU Plan aims for the EU to produce 10 million tonnes and import 10 million tonnes of renewable hydrogen by 2030.

On top of the regulatory framework, the Commission is also supporting the emergence of the hydrogen sector in the EU via Important Projects of Common European Interest (IPCEIs). The first IPCEI, called "IPCEI Hy2Tech", which includes 41 projects and was approved in July 2022, aims at developing innovative technologies for the hydrogen value chain to decarbonise industrial processes and the mobility sector, with a focus on end-users. In September 2022, the Commission approved "IPCEI Hy2Use", a second project which complements IPCEI Hy2Tech and which will support the construction of hydrogen-related infrastructure and the development of innovative and more sustainable technologies for the integration of hydrogen into the industrial sector.

More Information

Nanotech Energy, Inc. Reveals Plans for New £1bn UK Gigafactory

US battery manufacturer Nanotech Energy, Inc. has revealed it is investigating seven sites in the UK as the final location for a potential £1bn new Gigafactory.

The final decision, which will be made based on a combination of technical aspects and strategic alignments with OEM partners, could see the UK become a second home for the production of Nanotech Energy's patented, high-performing, non-flammable graphene-powered lithium-ion batteries.

If the project is given the go-ahead, it will complement Nanotech Energy's 517-acre manufacturing facility in Storey County, Nevada, where the first building is due to open in Q4 2022 and full battery production will begin in 2024.

Dr. Jack Kavanaugh, chairman, CEO and co-founder of Nanotech Energy, said: "Battery storage is finally set to fulfil its potential. After more than seven years of R&D, Nanotech Energy's non-flammable lithium-ion batteries are among the safest and most environmentally friendly options on the market. They also offer significantly better recharge speeds and greater storage capacities than traditional batteries, and moving into a new phase of production at our proposed £1bn Gigafactory will dramatically accelerate the advance of the UK's EV sector."

The batteries produced by Nanotech Energy have the capacity to revolutionise the performance of consumer electronics, electric vehicles, marine equipment, power walls, energy storage, and military hardware.

By using electrodes based on graphene, and then enhancing them with a proprietary non-flammable electrolyte, Nanotech Energy's batteries provide the ultimate solution in safety and performance.

Learn more

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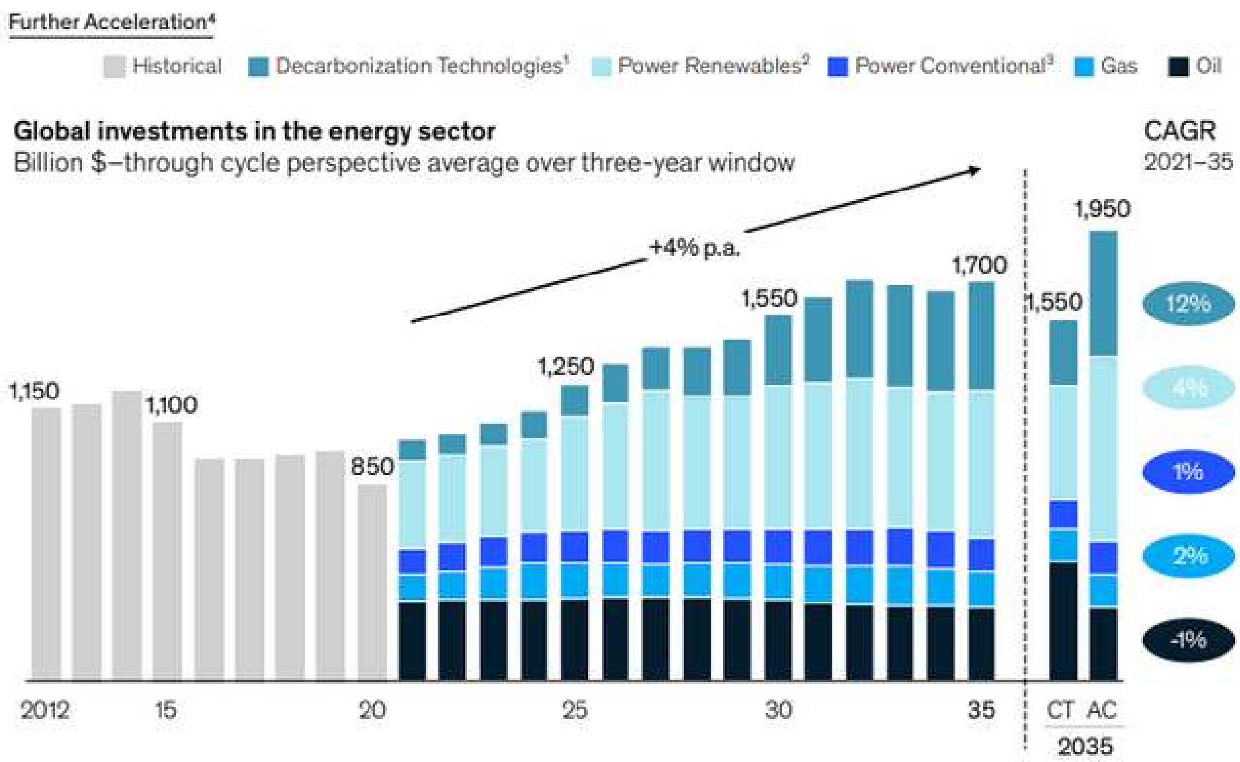
Engineered Nanomaterials could replace Critical Minerals in Clean Energy Technologies

Carbon nanomaterials as potential substitutes for scarce metals
Journal of Cleaner Production
Volume 156, 10 July 2017, Pages 253-261

Energy may attract increasing investment, with most growth being in RES and decarbonization technologies

(McKinsey)

Despite decline in underlying fossil-fuel demand, investments in O&G are expected to remain stable



1. Includes sustainable fuels, CCUS, hydrogen, and EV charging
2. Includes solar, onshore wind, o shore wind, hydro, and other
3. Includes coal, gas, nuclear, and other
4. For the O&G segments the 2021 Accelerated Transition Scenario is used in combination with Further Acceleration and Achieved Commitments, and the 2021 Reference Case Scenario with Current Trajectory

Total annual investments in the energy supply sector are projected to grow by 4% per year in the Further Acceleration scenario.

Driven by a significant uptake of demand for clean technologies—such as 15% CAGR for renewable power generation and 5% CAGR for hydrogen demand between 2019 and 2035—for the energy transition, almost all growth is driven by renewables power and decarbonization technologies.

Read the full report

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