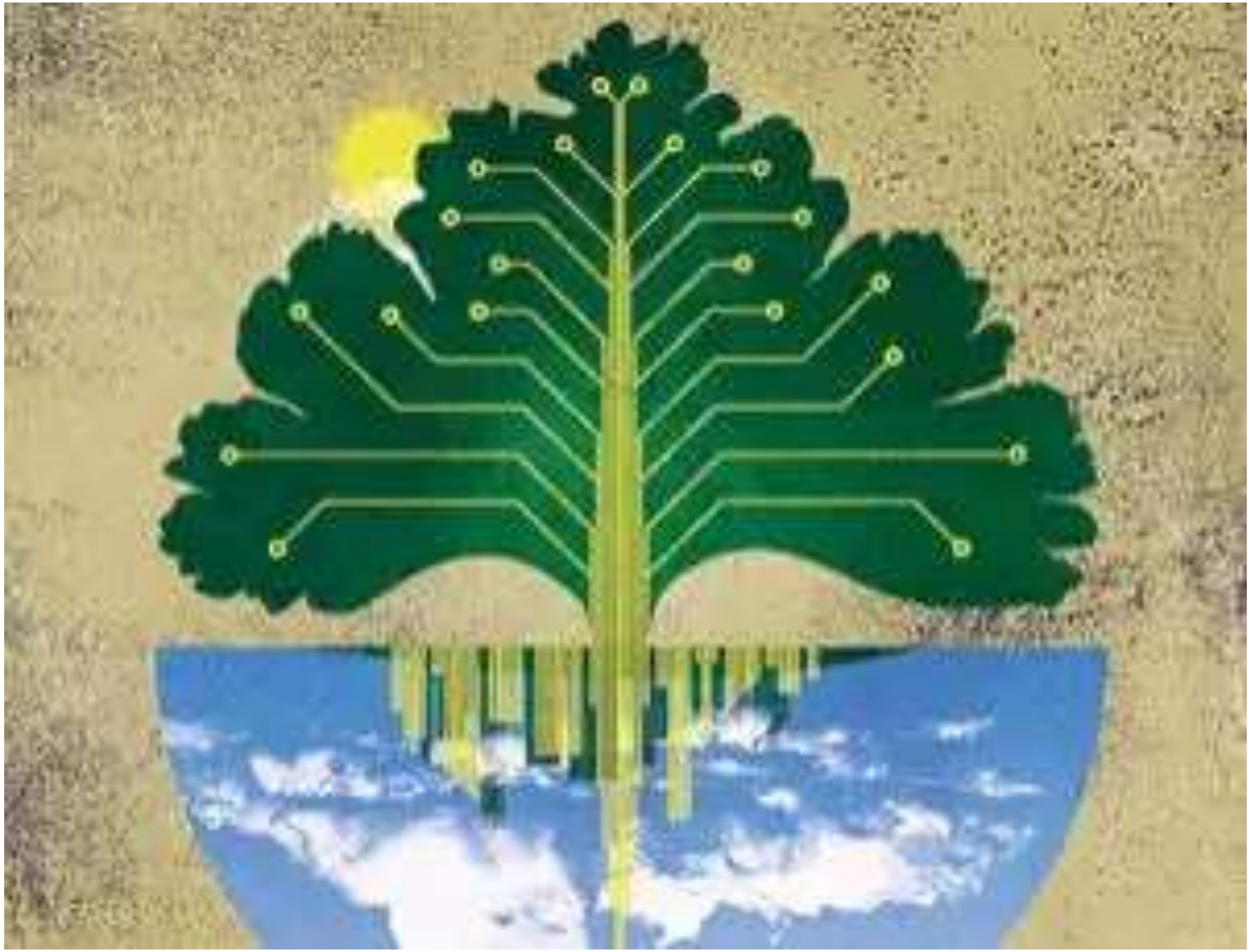
ARTIFICIAL PHOTOSYNTHESIS



COMPILED BY HOWIE BAUM

PHOTOSYNTHESIS

Photosynthesis is a process used by

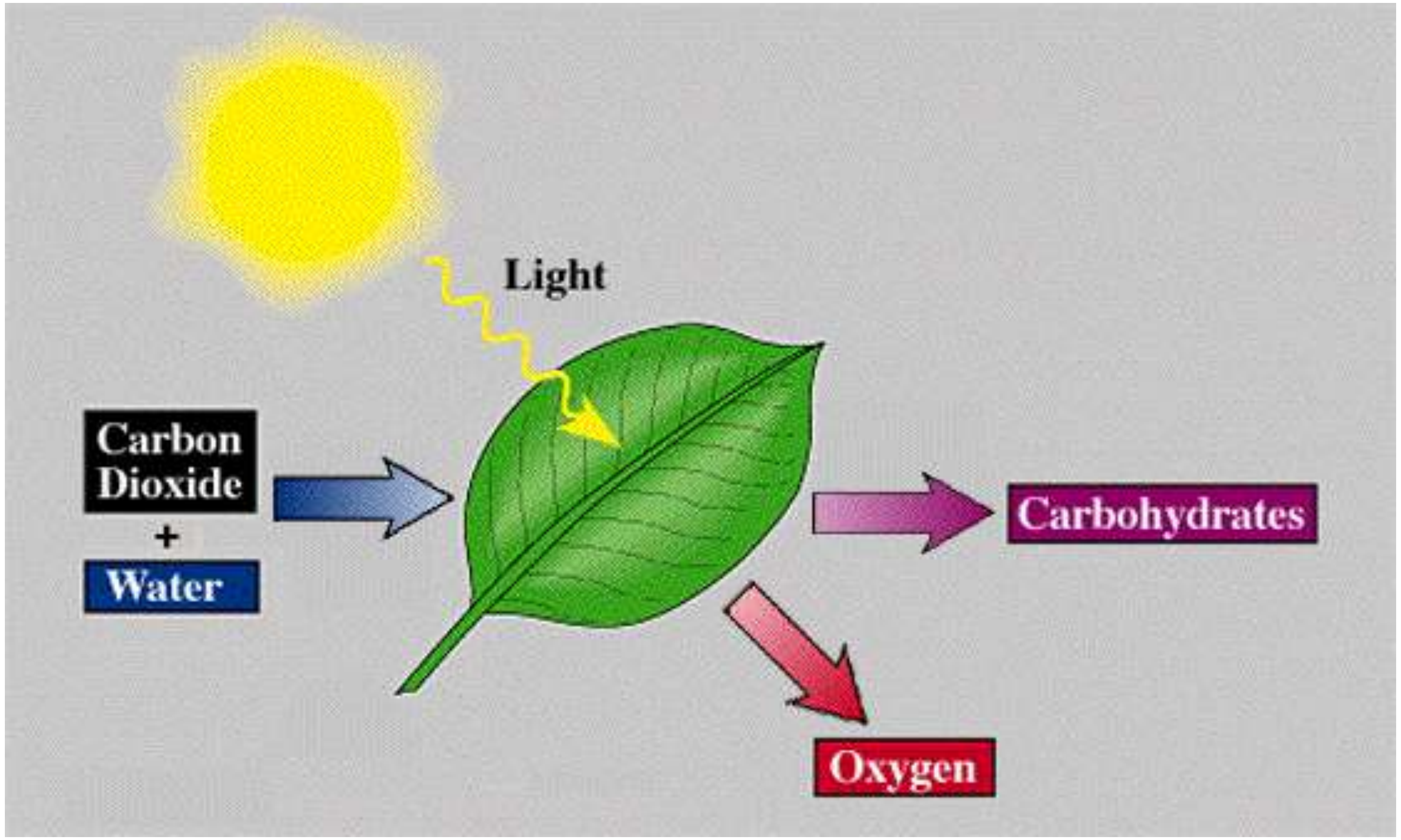
1) Plants

2) Algae

3) Cyanobacteria (blue-green algae)

to **convert light energy into chemical energy** that can later be released to fuel their growth.

This chemical energy is stored in carbohydrate molecules, such as sugars like **Glucose**, which are synthesized from carbon dioxide and water.



GLUCOSE

Glucose isn't just food for the plant.

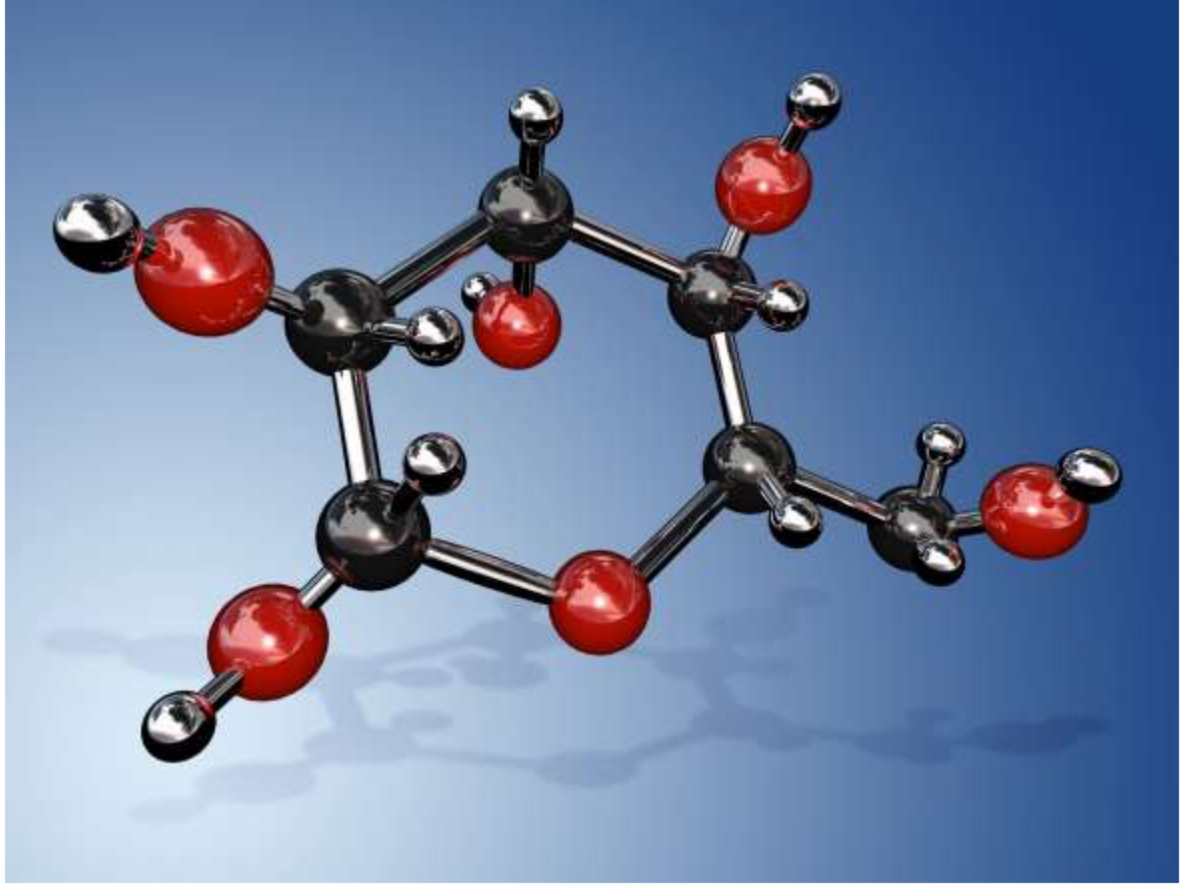
Glucose is a simple sugar, yet it is a large molecule compared to carbon dioxide or water.

While it is used for energy, it has other purposes, too.

For example, plants use glucose as a building block to build:

1) **Starch for long-term energy storage**

2) **Cellulose** to build plant structures.



Black spheres – Carbon atoms (6)

Red spheres – Oxygen atoms (6)

Silver end spheres – Hydrogen atoms (11)

Science Photo Library - MIRIAM MASLO. / Getty Images

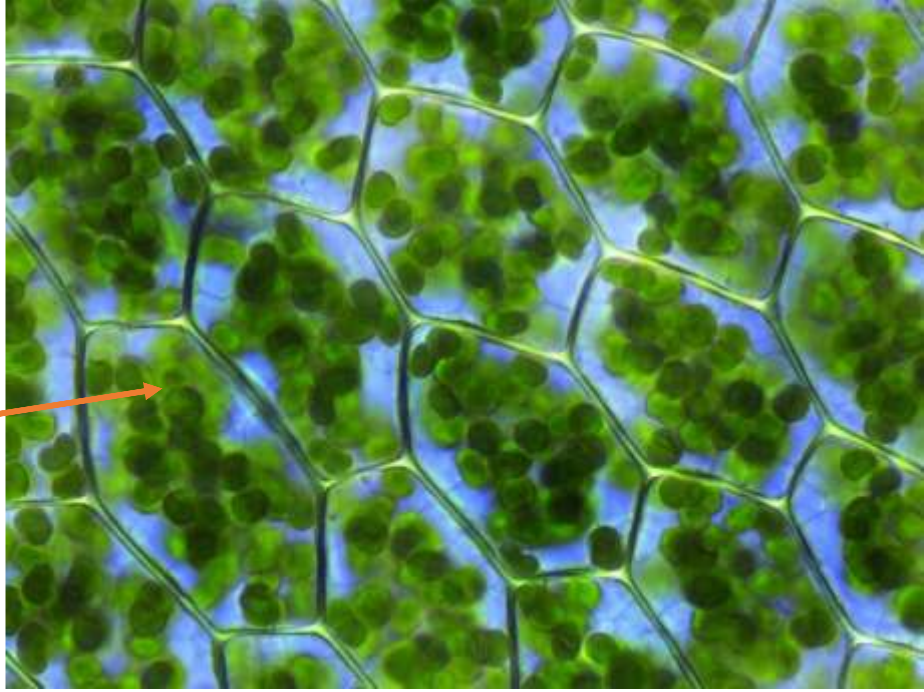
CHLOROPHYLL

The most common molecule used for photosynthesis is chlorophyll.

Plants are green because their cells contain an abundance of chlorophyll in small spheres called chloroplasts.

Chlorophyll absorbs the solar energy that drives the reaction between carbon dioxide and water.

Phyto-plankton, the microscopic floating plants that form the basis of the entire marine food web, also contain chlorophyll, which is why high phyto-plankton concentrations can make water look green.



This picture is a magnified image of plant cells from a Moss plant.

CHLOROPHYLL ISN'T THE ONLY PHOTOSYNTHETIC PIGMENT

Chlorophyll is not a single pigment molecule, but rather is a family of related molecules that share a similar structure.

There are also other pigment molecules that absorb/reflect different wavelengths of light.

In the autumn, leaves and Algae produce less chlorophyll, in preparation for winter.

As chlorophyll production slows, leaves and Algae change color.

You can see the red, purple, and gold colors of other photosynthetic pigments but the important thing is that they still convert light into the food for the plant or tree, until the leaves come off the tree or plant, in the Fall.

Jenny Dettrick / Getty Images

ENERGY EFFICIENCY OF PLANTS AND SOLAR CELLS

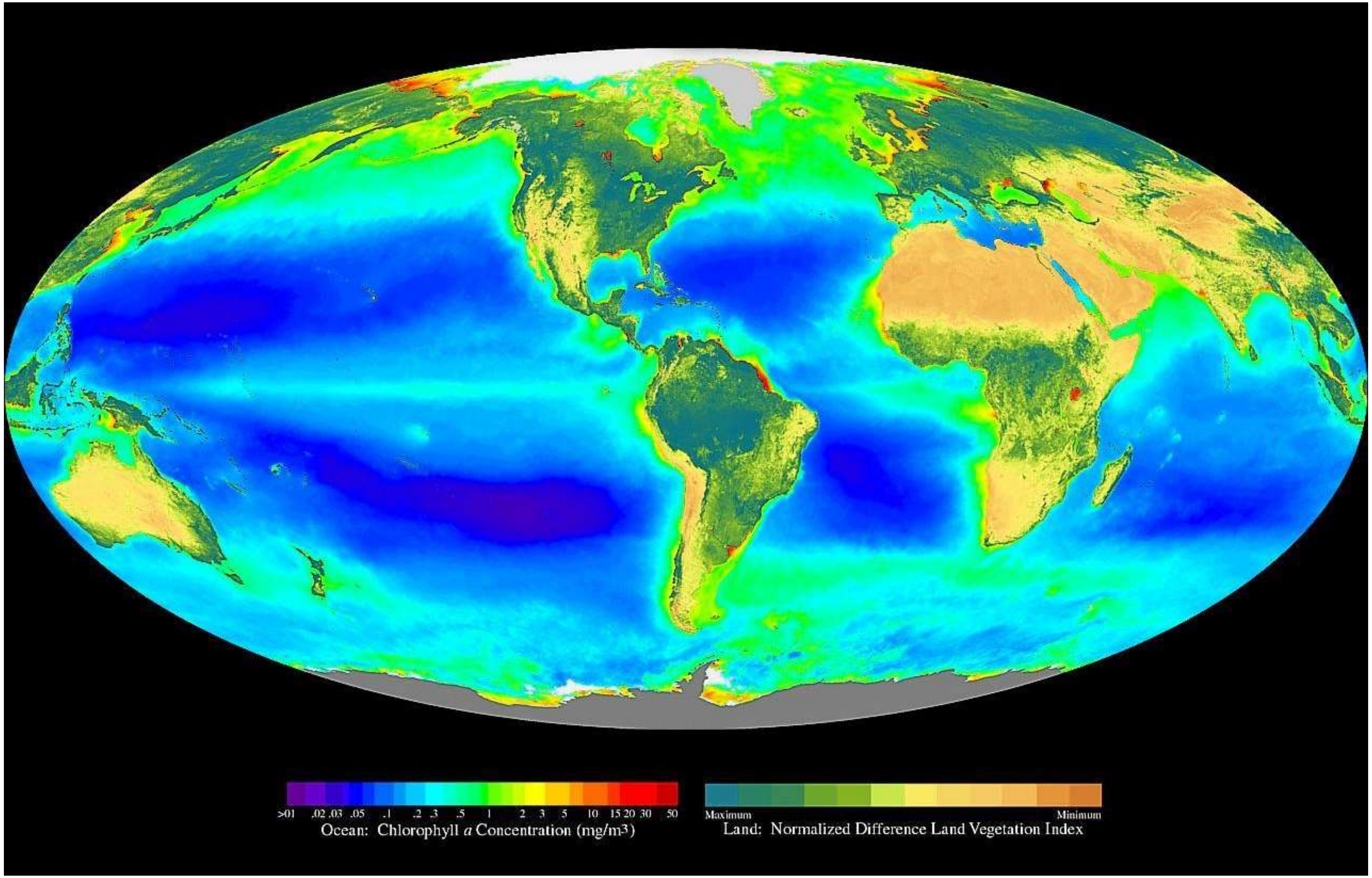
Plants usually convert light into chemical energy with a photosynthetic efficiency of **3–6%**.

By comparison, **solar panels** convert light into electric energy at an efficiency of approximately **6–20%** for mass-produced panels.

Composite image showing **the global distribution of photosynthesis,** including both oceanic phyto-plankton and terrestrial vegetation.

Dark red and blue-green indicate regions of high photosynthetic activity in the ocean and on land, respectively.

Because food webs in every type of ecosystem, from terrestrial to marine, begin with photosynthesis, chlorophyll can be considered a foundation for all life on Earth.



Provided by the SeaWiFS Project, Goddard Space Flight Center and ORBIMAGE - http://oceancolor.gsfc.nasa.gov/SeaWiFS/BACKGROUND/Gallery/index.html and from en:Image:Seawifs g biosphere.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=387228

AMAZING DESIGN OF PLANTS FOR PHOTOSYNTHESIS

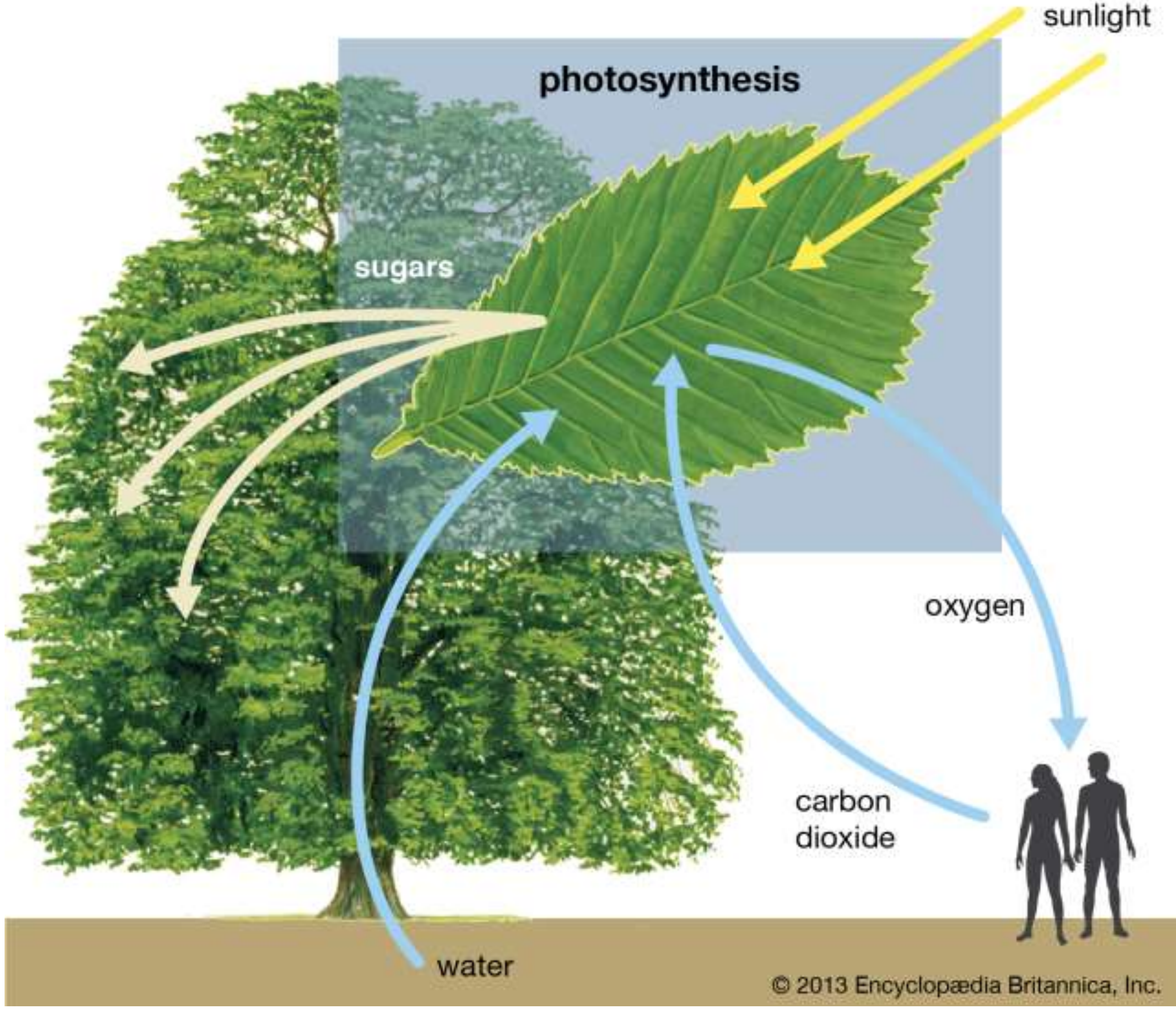
Plants are wizards as far as photosynthesis is concerned.

Their entire structure is built to support the process.

The plant's roots are designed to absorb water, which is then transported by a special vascular tissue called xylem, so it can be available in the photosynthetic stem and leaves.

Leaves contain special pores called stomata that control gas exchange and limit water loss.

Leaves may have a waxy coating to minimize water loss.



Origins of Energy

All energy comes from the stars

- **Solar Energy** -- from the sun - **(Photosynthesis)**
- **Chemical Energy**—from the oxidation of atoms/molecules that were created in the stars
- **Biomass Energy**—from combustion of plants that grow as result of sun light along with combining elements created in stars
- **Nuclear Energy**– from radioactive decay of elements created in the stars
- **Wind Energy**– from atmosphere's convection currents driven by solar energy and earth's rotation
- **Hydroelectric Energy**—from rain cycle driven by the sun

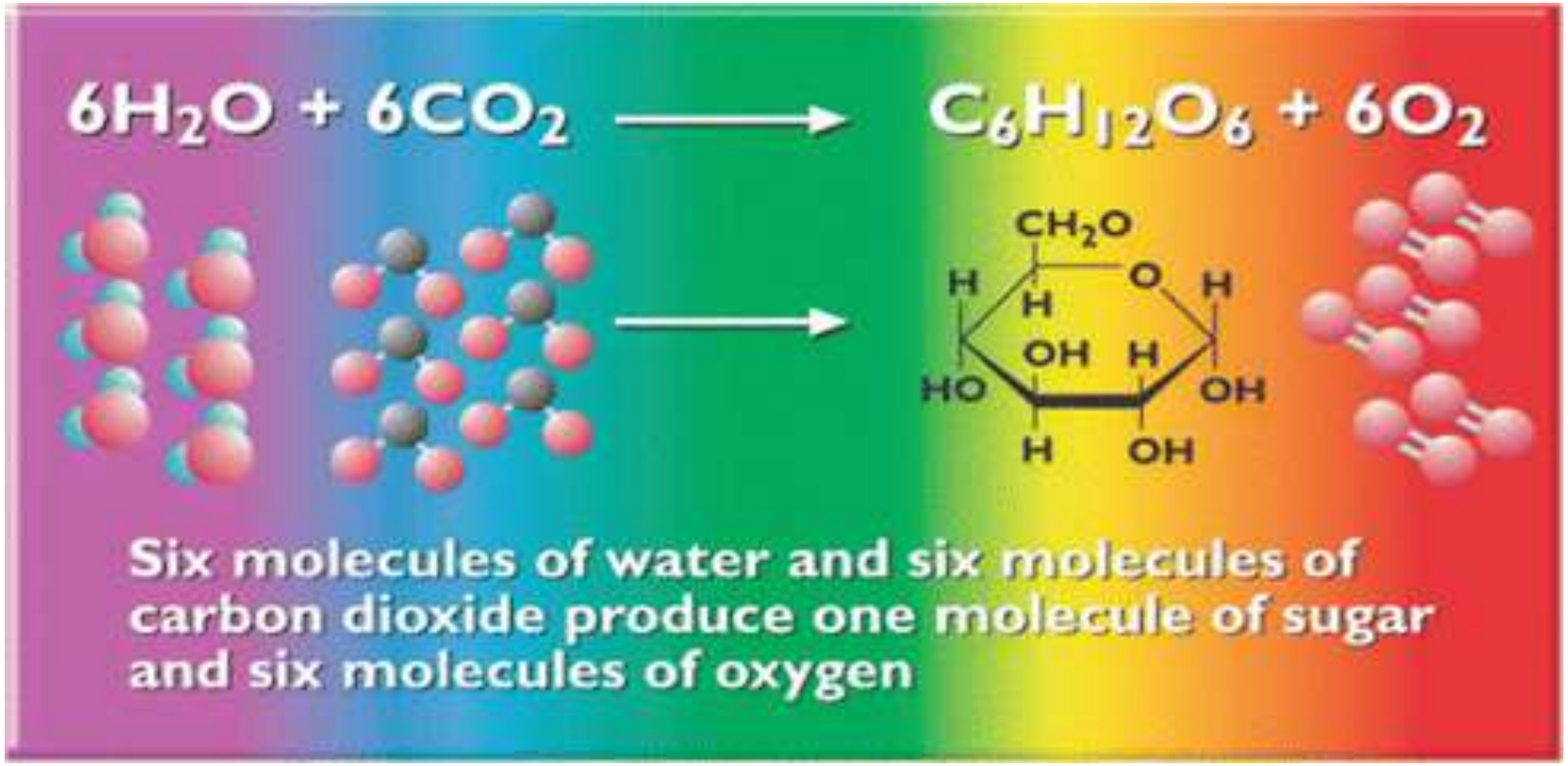
Today, the average rate of energy capture by photosynthesis globally is approximately 130 terawatts (130 trillion watts) per year, which is about eight times the current power consumption of human civilization.

Photosynthetic organisms also convert around 100–115 billion tons of carbon into biomass per year.

PRODUCING OXYGEN FROM PHOTOSYNTHESIS

Photosynthesis is largely responsible for producing and maintaining the oxygen content of the Earth's atmosphere.

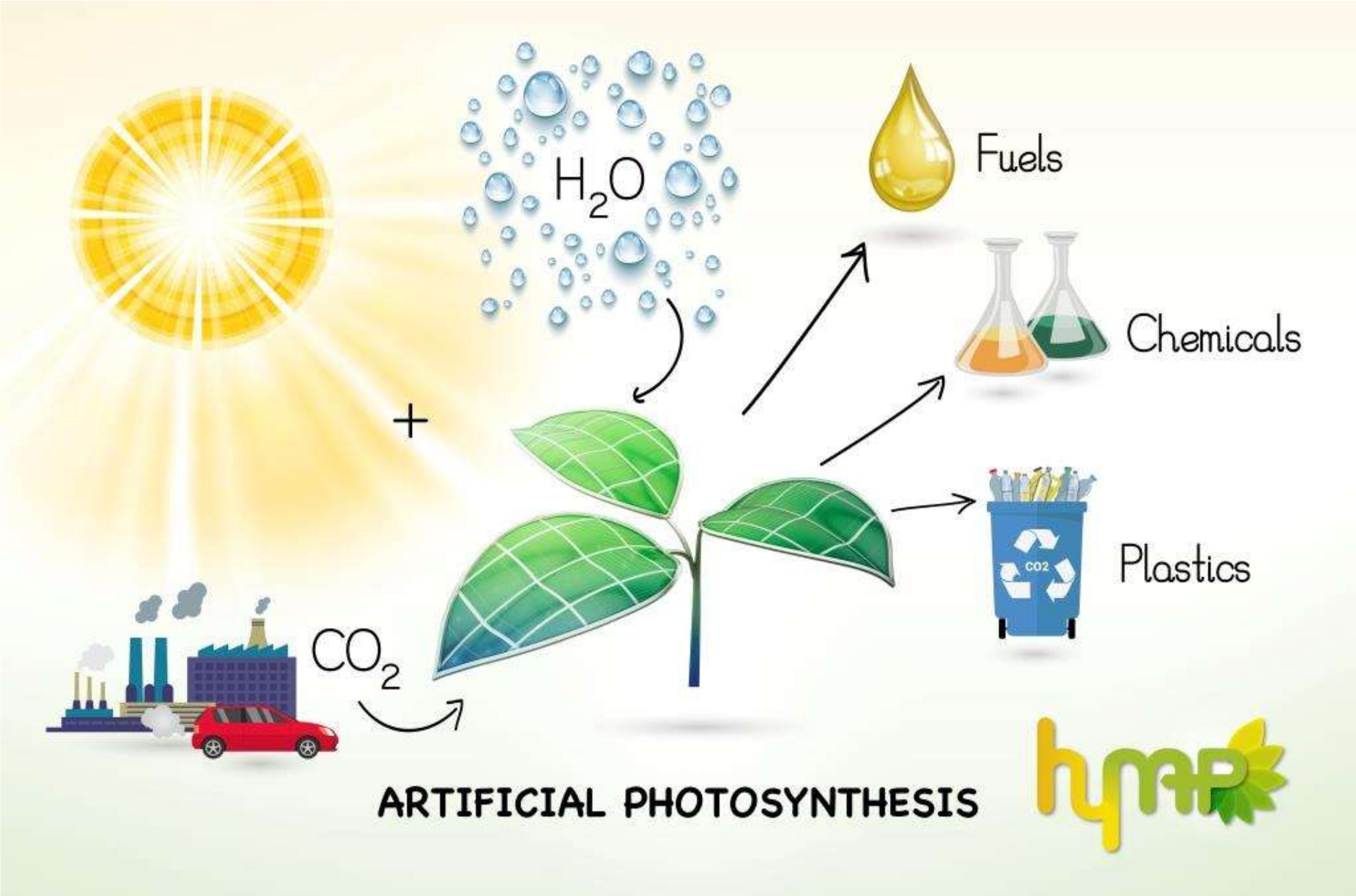
It supplies most of the energy and Oxygen necessary for life on Earth.



ARTIFICIAL PHOTOSYNTHESIS

"The goal of artificial photosynthesis is to mimic the green plants and other photosynthetic organisms in using sunlight to make high-energy chemicals but with far higher efficiencies and simplicity of design for scale-up and large-scale production."

Thomas J. Meyer Professor of Chemistry at the University of North Carolina, Chapel Hill,



WHAT ARE THE REASONS FOR USING ARTIFICIAL PHOTOSYNTHESIS ?

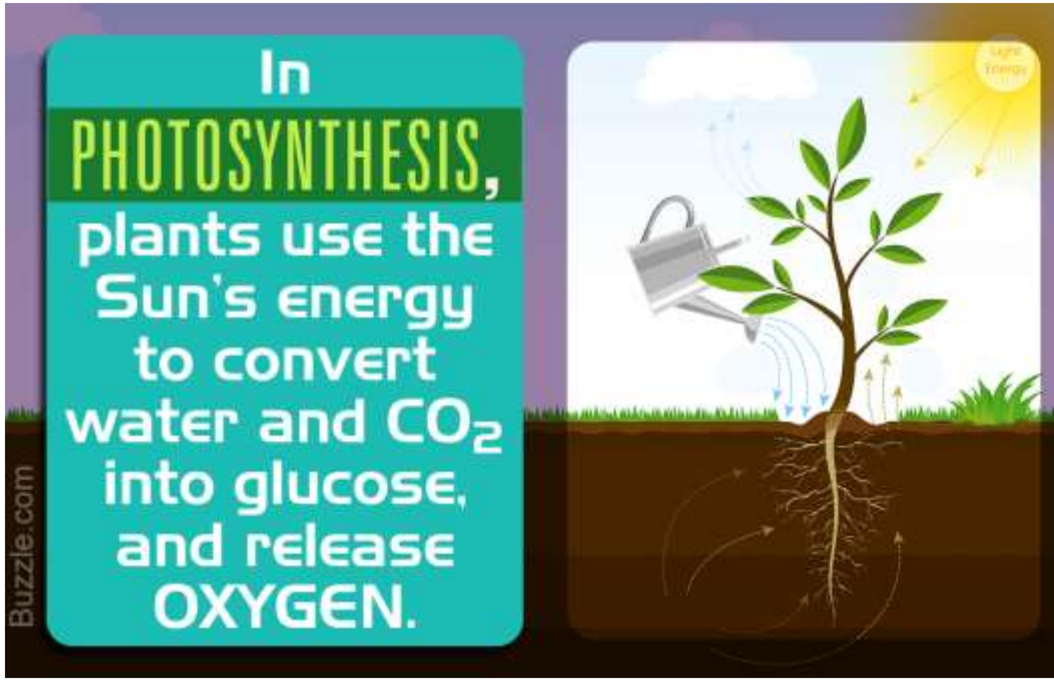
1) To create chemical energy in the form of Carbohydrates from sunlight like Glucose and other compounds, like regular photosynthesis does but on a bigger scale.

2) To separate Oxygen and/or Hydrogen from water, from new technology processes, using light

3) To break the bonds of the Carbon Dioxide (CO_2) molecule so that oxygen gas and Carbon can be produced and stored separately.

4) Remove the excess of Carbon Dioxide from the air to reduce the effects of Global Warming.

5) It can also decrease the concentration of carbon dioxide and other harmful industrial wastes that leads to respiratory problems in living beings.



CATALYST

It is a substance that increases the rate of a chemical reaction without itself undergoing any permanent chemical change.

ELECTROLYSIS

Electrolysis is the decomposition of water into oxygen and hydrogen gas due to the passage of an electric current.

This technique can be used to make hydrogen gas, a main component of hydrogen fuel, and breathable oxygen gas.

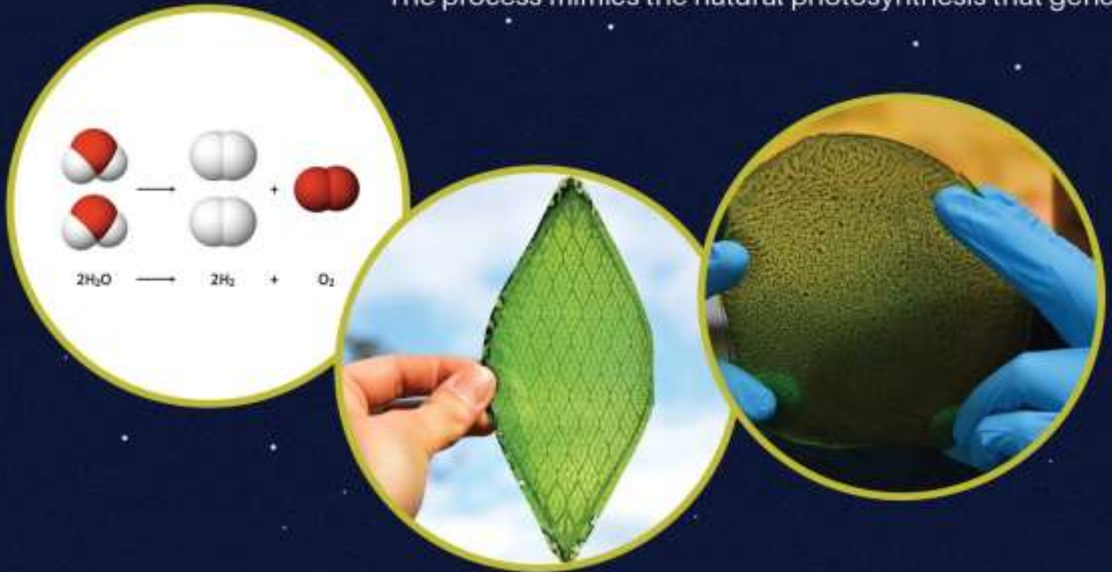
It is also called water splitting. It requires a minimum potential difference of 1.23 volts to split water.

ARTIFICIAL PHOTOSYNTHESIS

THE ENERGY SOURCE OF THE FUTURE

HOW DOES IT WORK?

Artificial photosynthesis uses a solar-powered device, called an artificial leaf, which converts sunlight and water into hydrogen and oxygen (splitting water). The hydrogen could then be used directly as liquid fuel or channeled into a fuel cell. The process mimics the natural photosynthesis that generates energy for plants through plant leaves.



BENEFITS OF ARTIFICIAL PHOTOSYNTHESIS

STORAGE

The current technologies that generate power from solar energy lack something important: the ability to store energy. Artificial photosynthesis solves this problem by making the final product into a storable fuel.

DIFFERENT TYPES OF FUELS

Artificial photosynthesis has the potential to produce more than one type of fuel. The final product could be liquid hydrogen, which can be used like gasoline in hydrogen-powered engines, or methanol, which can be used to directly run cars.

NO NEED TO RECHARGE ELECTRONICS AGAIN

Electronics could automatically recharge when they are getting low on power by simply absorbing and storing energy from the sun.

REDUCE GLOBAL WARMING

The use of artificial photosynthesis on a momentous scale could take in and clean up the excessive amounts of carbon dioxidein our atmosphere and reverse the harmful effects of the greenhouse effect.

MORE FOOD – EVERYWHERE!

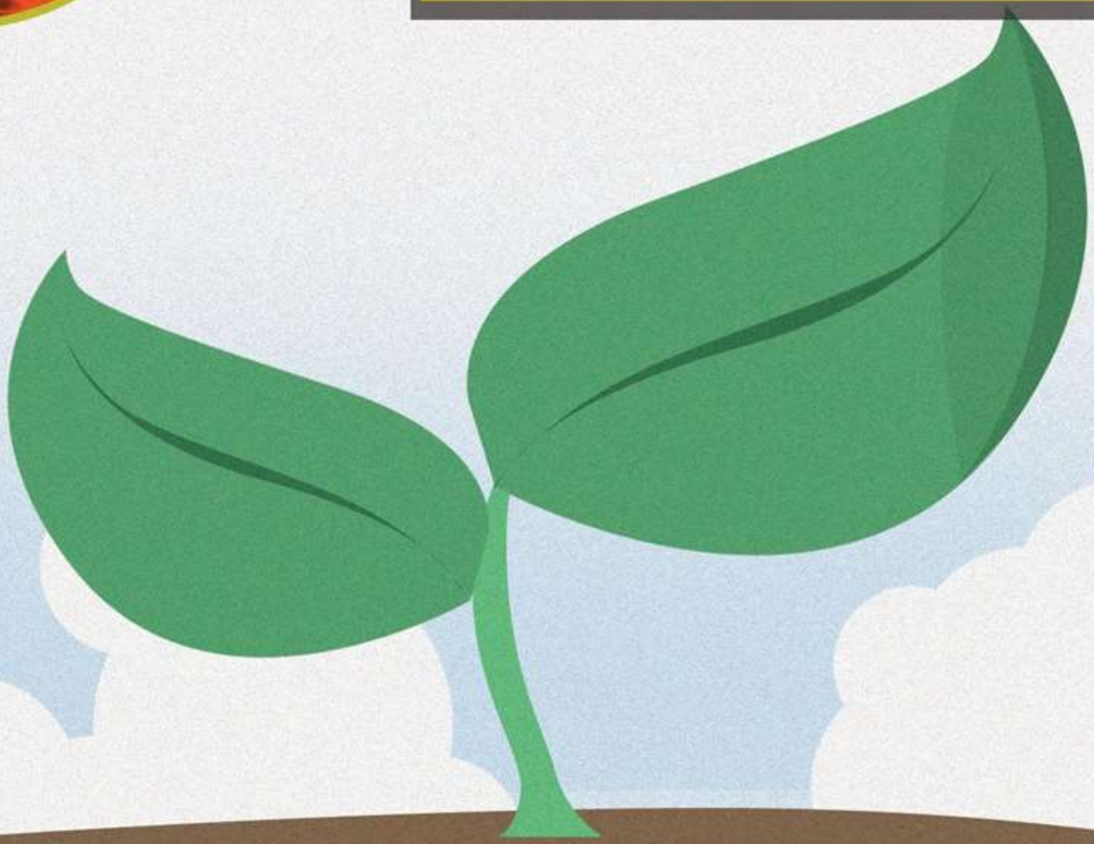
Artificial photosynthesis could help solve the global food shortage here on Earth, and could help produce food for future space colonies. Nature's photosynthesis synthesizes carbohydrates, the source of food on which virtually all life depends on. By mastering photosynthesis, the amount of farming needed would substantially decrease and world hunger would diminish.

SPACE SURVIVAL

If the processes of artificial photosynthesis were mastered, it would be possible to take the CO2 and urine given off by the astronaut and convert it to oxygen and food. This would make space colonies a much more realistic vision and allow for trips of longer duration.

FREE AND UNLIMITED ENERGY SUPPLY

For as long as the sun lives. The sun is expected to die when its core runs out of hydrogen in about 6 billion years. By then, humans would have found a new home.

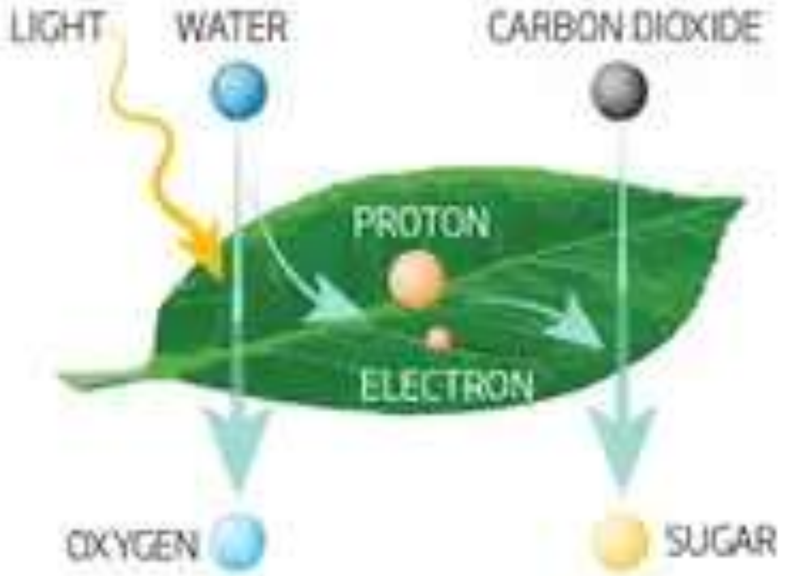


Green machines

A new generation of sunlight harvesters will be more useful than ever before

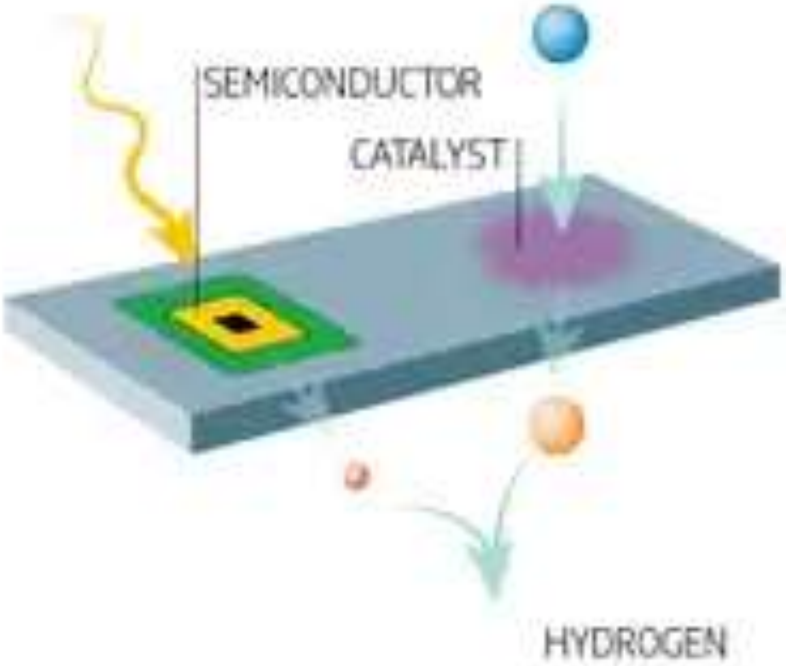
Natural leaf

During the day, plants take in water and carbon dioxide. They use light and a menagerie of enzymes to convert these into oxygen and sugar



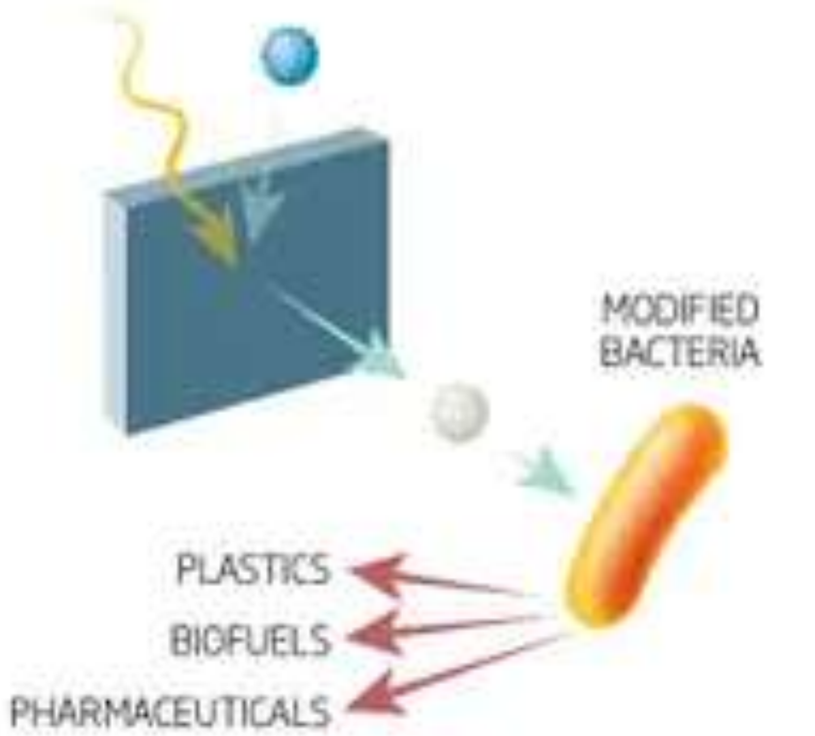
Artificial leaf

Synthetic leaves have a semiconductor to generate electrons from light, and a catalyst to steal protons from water. These are combined to make hydrogen



Bionic leaf

These combine light-harvesting tech with microbes. In one design, hydrogen from an artificial leaf is passed to microbes, which then produce useful chemicals



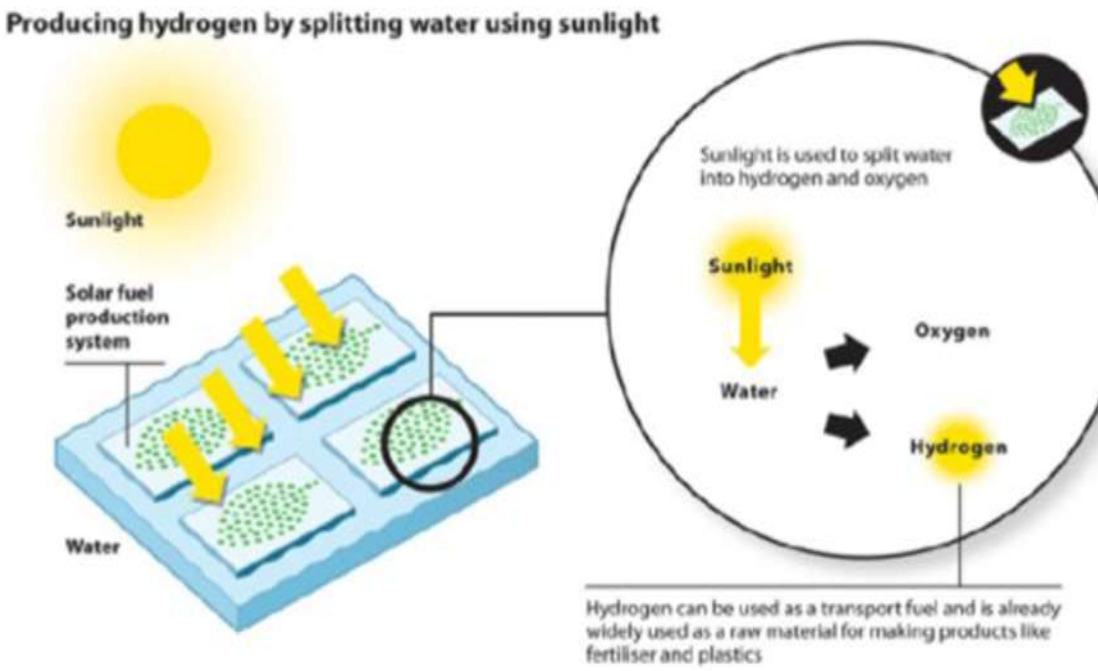
METHODS FOR ARTIFICIAL PHOTOSYNTHESIS

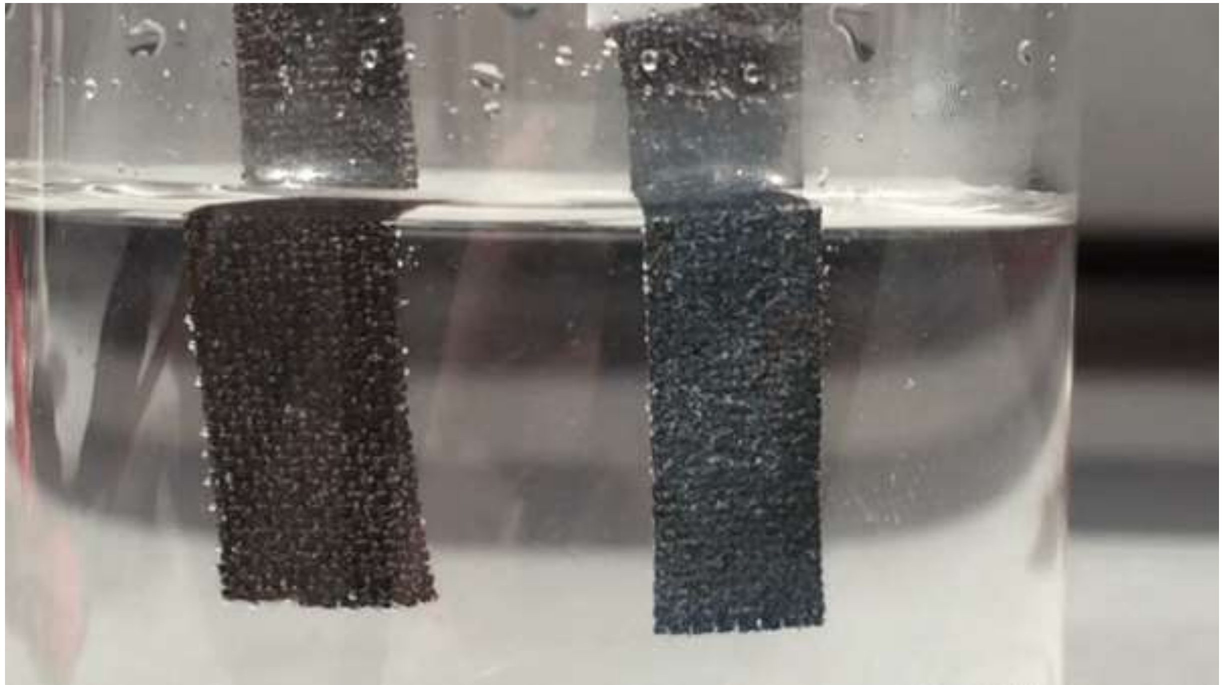
Artificial photosynthesis is a chemical process that bio-mimics the natural process of photosynthesis to convert sunlight, water, and carbon dioxide into carbohydrates (usually sugars for energy) and oxygen.

Photo-catalytic water splitting converts water into hydrogen and oxygen gases and is a major research topic of artificial photosynthesis.

https://www.youtube.com/watch?v=miUNlYg7O9E (40 seconds)

https://www.youtube.com/watch?v=dhj9YrX-CK8 1.5 minutes

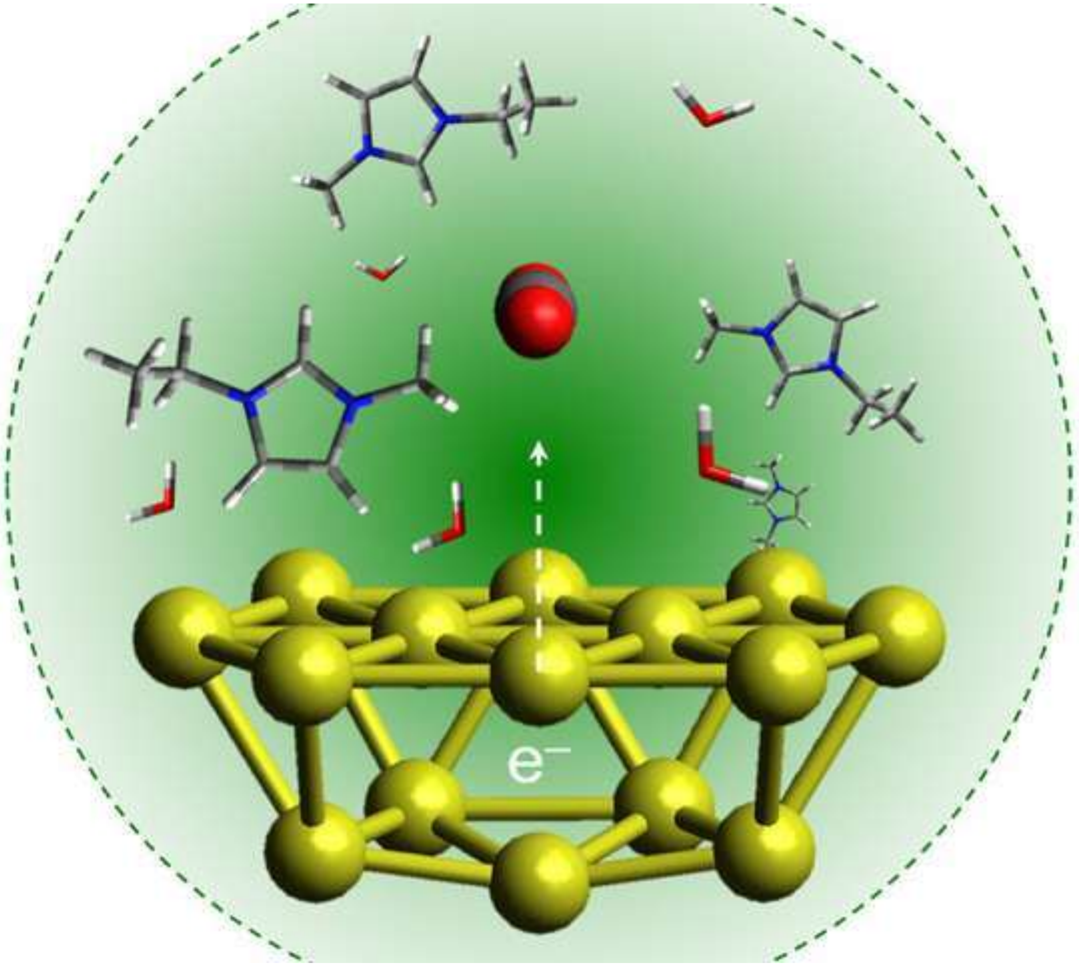




ARTIFICIAL PHOTOSYNTHESIS TRANSFORMS CARBON DIOXIDE INTO LIQUEFIABLE FUELS

Chemists at the University of Illinois have successfully produced fuels using water, carbon dioxide and visible light through artificial photosynthesis.

Under green light and assisted by an ionic liquid with gold nanoparticles at the bottom, lend electrons to convert CO2 molecules, the red and grey spheres in the center, to more complex hydrocarbon fuel molecules.



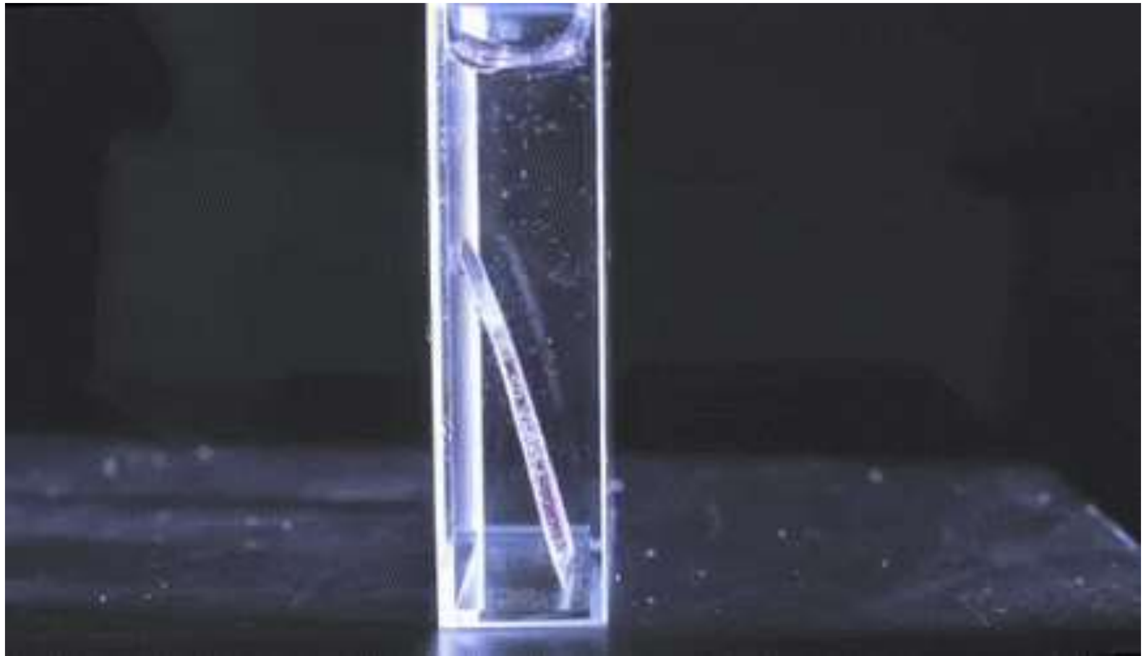
Credit: Graphic courtesy Sungju Yu, Jain Lab at University of Illinois at Urbana-Champaign

THE ARTIFICIAL LEAF

An 'artificial leaf' made by Daniel Nocera and his team from MIT, uses a silicon solar cell with novel catalyst materials bonded to its two sides, is shown in a container of water with light (simulating sunlight) shining on it.

The light generates a flow of electricity that causes the water molecules, with the help of the catalysts, to split into oxygen and hydrogen, which each bubble up from the two opposite sides.

https://www.youtube.com/watch?v=sSo005x9hCc

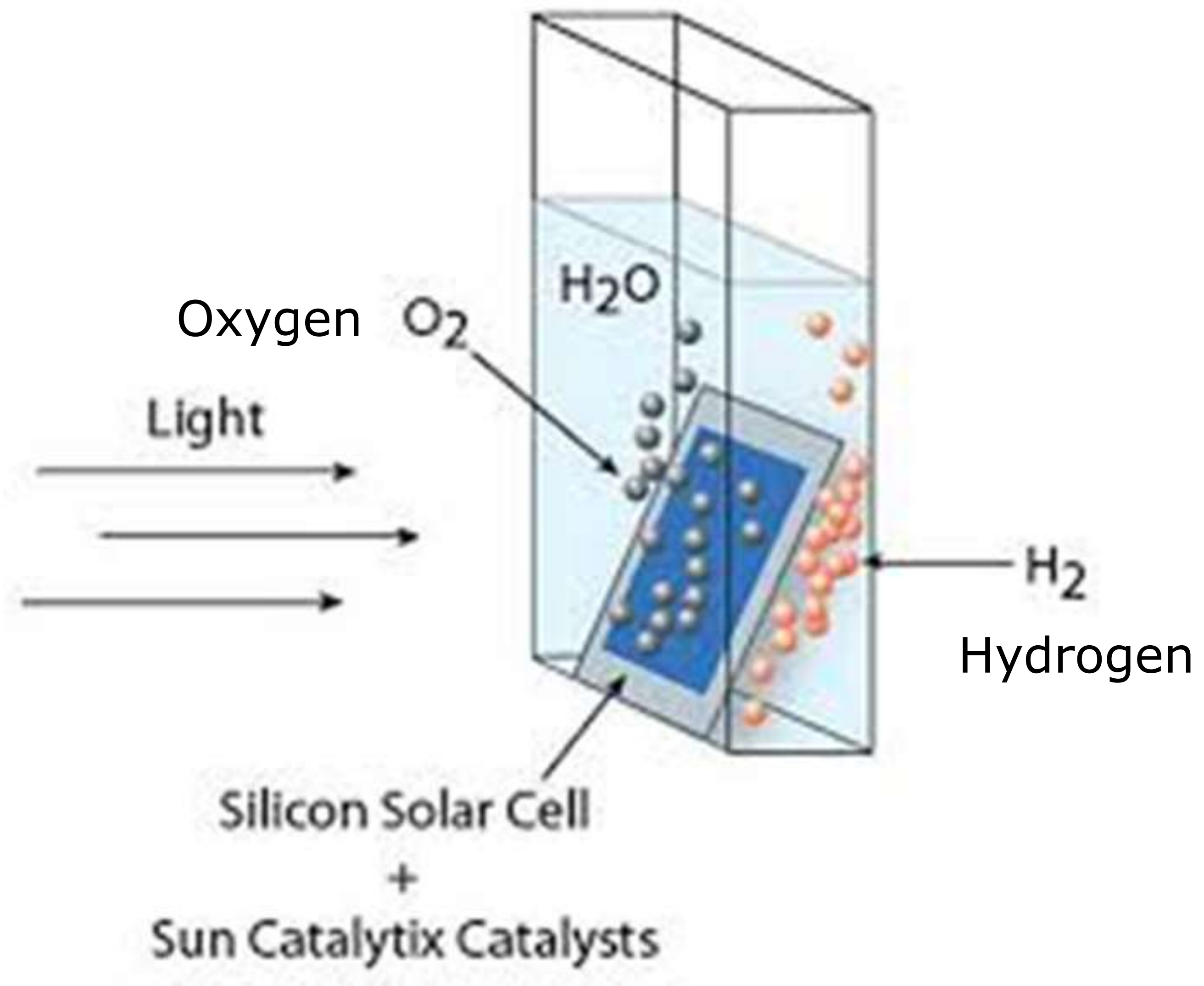


The device, Nocera explains, is made entirely of earth-abundant, inexpensive materials — mostly silicon, cobalt and nickel instead of expensive Platinum — and works in ordinary water.

The artificial leaf is a thin sheet of semiconducting silicon — the material most solar cells are made of — which turns the energy of sunlight into a flow of wireless electricity within the sheet.

Bound onto the silicon is a layer of a cobalt-based catalyst, **which releases oxygen.**

The other side of the silicon sheet is coated with a layer of a nickel-molybdenum-zinc alloy, **which releases hydrogen** from the water molecules.

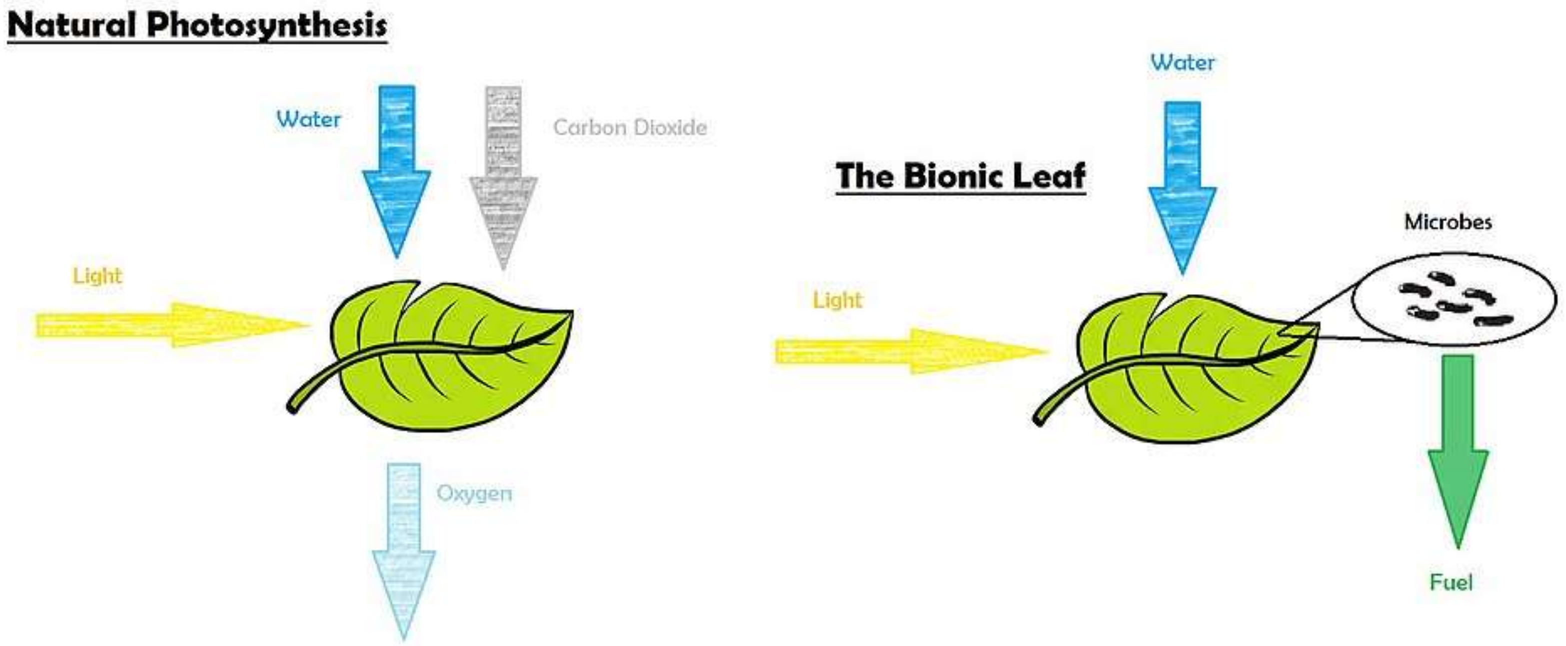


THE BIONIC LEAF

The Bionic Leaf is a bio-mimetic system that gathers solar energy via photovoltaic cells that can be stored or used in a number of different functions.

Bionic leaves can be composed of both synthetic (metals, ceramics, polymers, etc.) and organic materials (bacteria), or solely made of synthetic materials.

The Bionic Leaf has the potential to be implemented in communities, such as urbanized areas to provide clean air as well as providing needed clean energy.



THESE ARTIFICIAL LEAVES CAN ABSORB 10 TIMES MORE CO_2 FROM THE AIR THAN REAL LEAVES

1) The traditional artificial leaf is placed inside a water-filled capsule constructed out of a semi-permeable membrane.

2) When the sunlight warms the water, it evaporates through the membrane – when that happens it gets the capsule to suck in carbon dioxide (co_2).

3) The CO_2 that's been sucked in then gets converted into carbon monoxide (CO) and oxygen by the artificial leaf inside the capsule.

4) The carbon monoxide (CO) could be siphoned from the device and used to create synthetic fuels ranging from gasoline to methanol

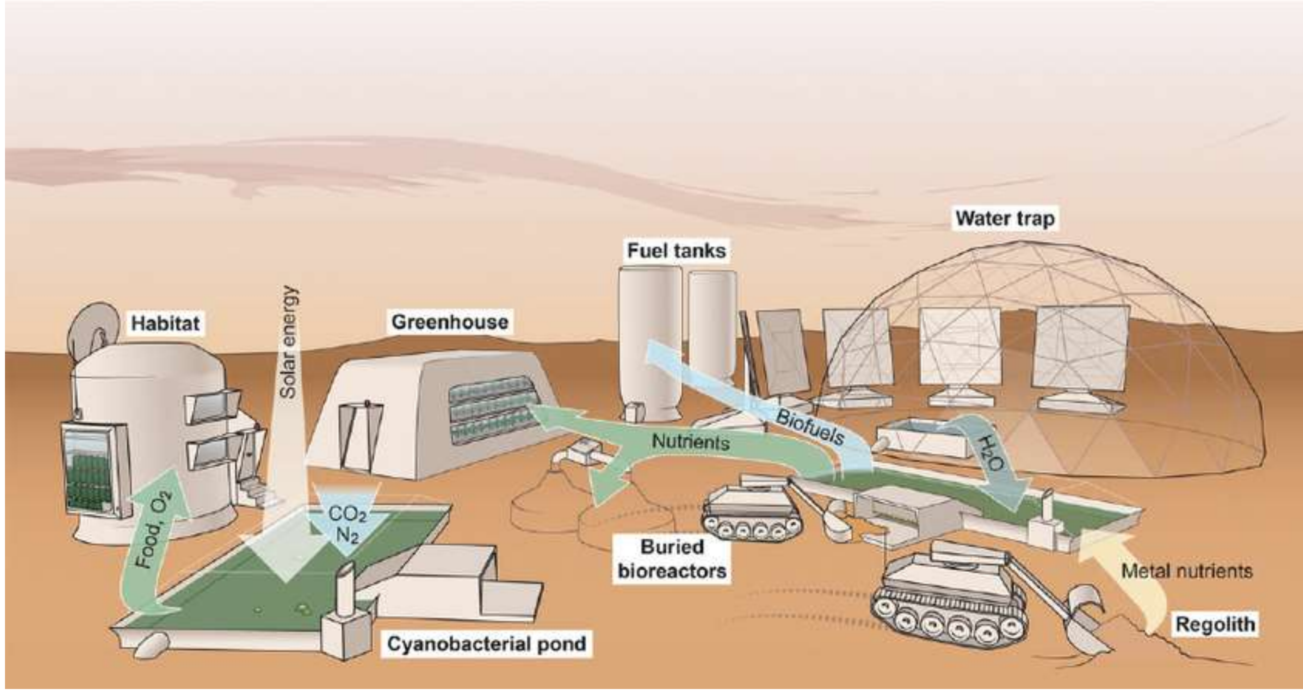
5) The oxygen is then released back into the environment or collected.

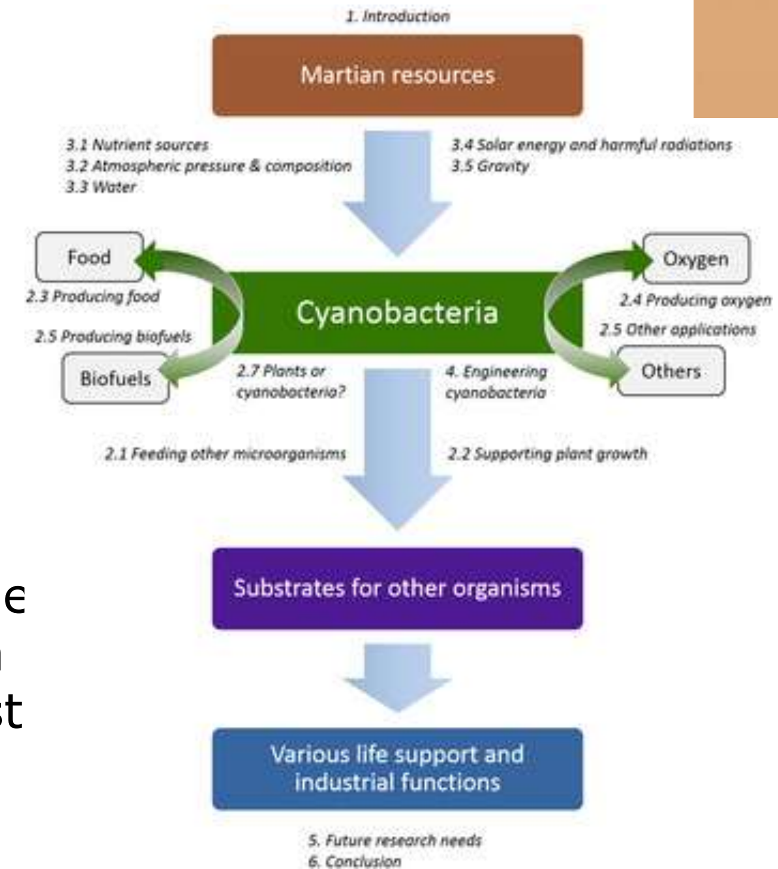
PRODUCING OXYGEN FOR BREATHING, ON MARS

If we can't figure out a way to breathe on Mars, what's the point of all of our colonization plans?

Now, we may have a new hope in the hunt for a steady supply of oxygen on the Red Planet: **cyanobacteria.**

This family of bacteria sucks up carbon dioxide and discharges oxygen in some of Earth's most inhospitable environments.



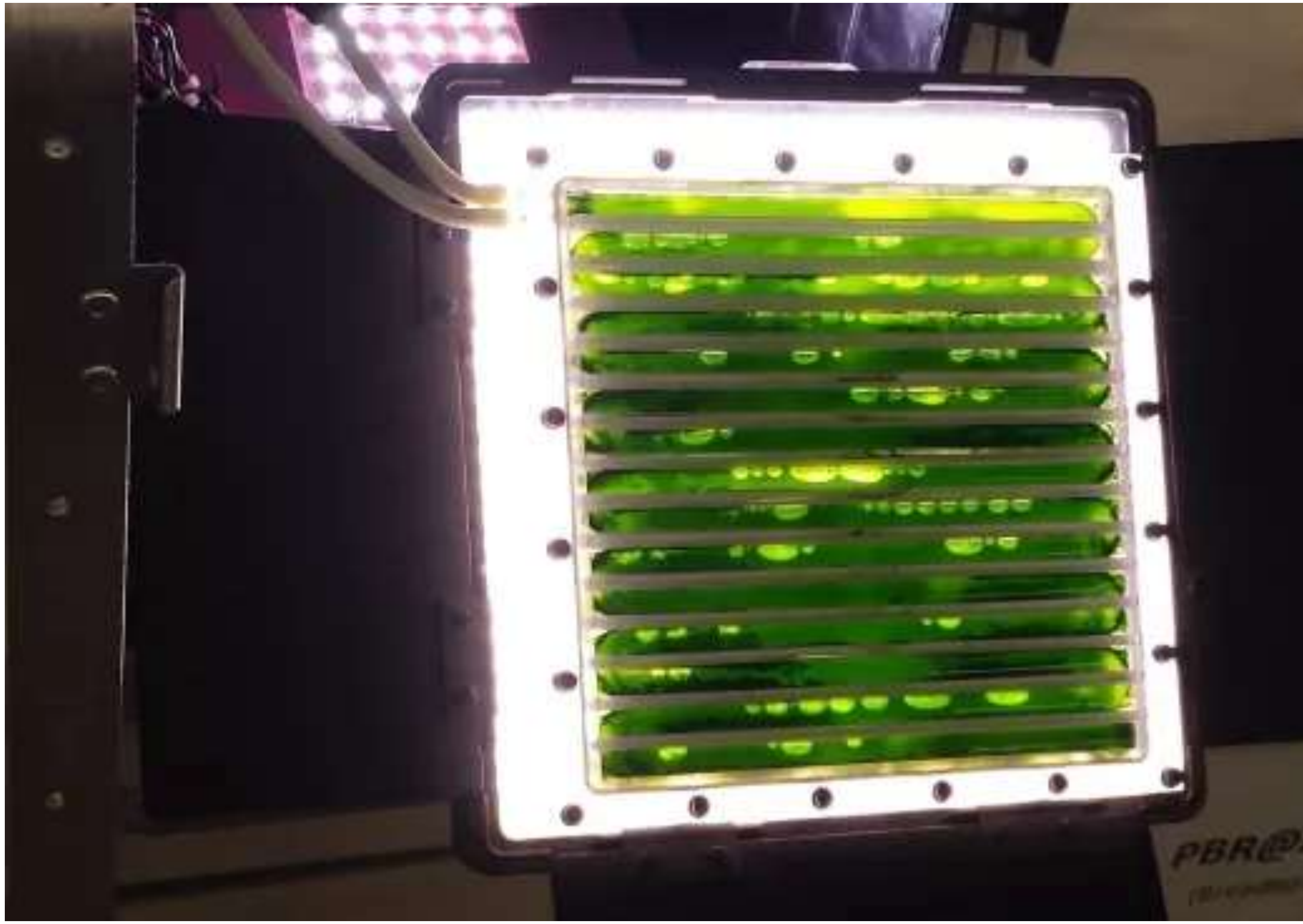


ALGAE 'BIOREACTOR' ON SPACE STATION COULD MAKE OXYGEN, AND FOOD FOR ASTRONAUTS

Astronauts on the International Space Station will begin testing an innovative algae-powered bioreactor to assess its feasibility for future long-duration space missions.

The algae-powered bioreactor, called the Photobioreactor, represents a major step toward creating a closed-loop life-support system, which could one day sustain astronauts without cargo resupply missions from Earth.

This will be particularly important for future long-duration missions to the moon or Mars, which require more supplies than a spacecraft can carry



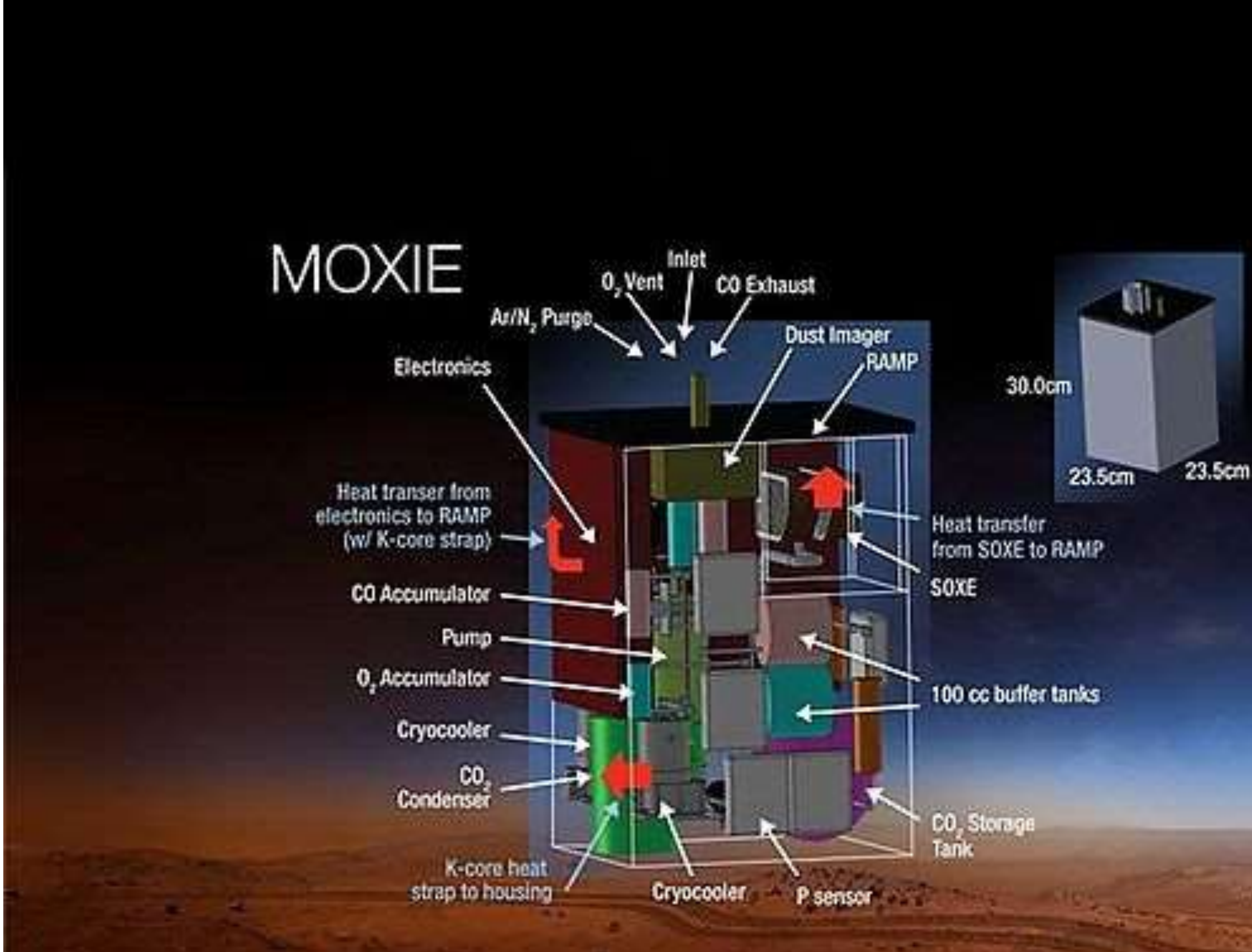
In the Photobioreactor, the green microalgae Chlorella vulgaris converts carbon dioxide into oxygen and edible biomass through photosynthesis.

(Image credit: IRS Stuttgart)

MOXIE

Mars Oxygen ISRU Experiment (MOXIE) is an exploration technology experiment that will produce a small amount of pure oxygen from Martian atmospheric carbon dioxide (CO_2) in a process called solid oxide electrolysis

MOXIE is a 1% scale model aboard the Perseverance rover, as part of the Mars 2020 mission.



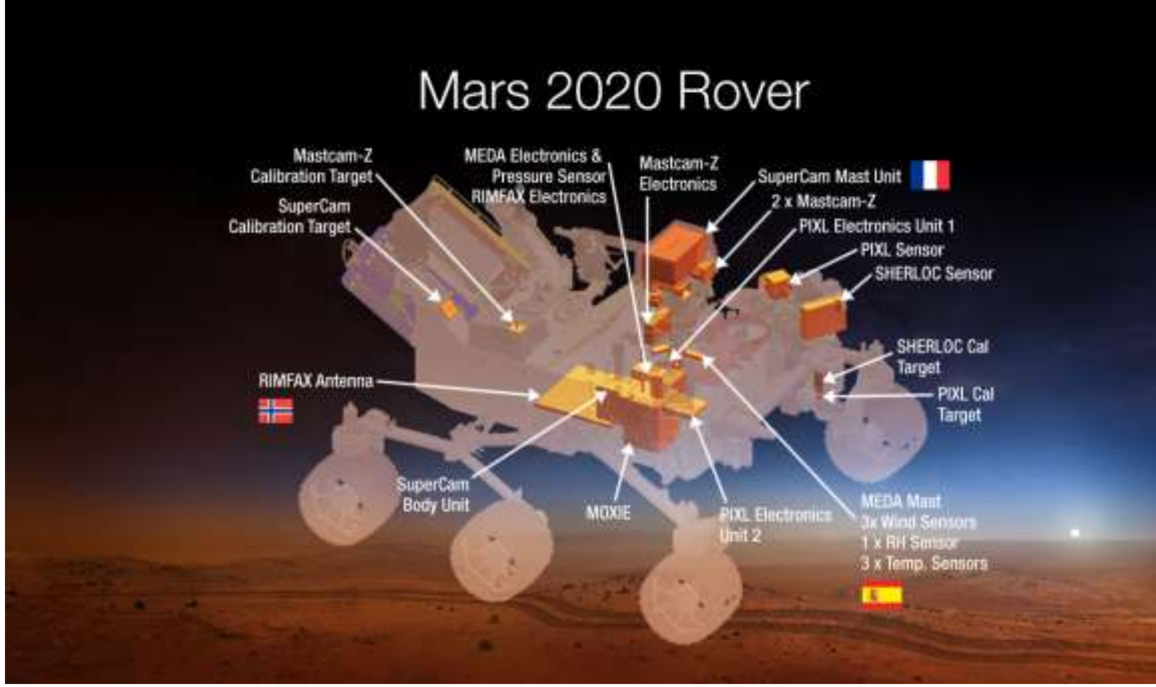
The main objective of this experiment is to produce molecular oxygen (O_2) from the **atmospheric carbon dioxide (CO_2) which makes up 96% of the Martian atmosphere.**

Scientists will record the efficiency of the O_2 production rate, and the resulting oxygen and carbon monoxide will be vented out after measurements are done.

To achieve this objective, the MOXIE instrument has a goal of producing 22 g of oxygen (O_2) per hour with more than 99.6% purity for 50 sols (Martian days) (~1230 hours).

NASA officials stated that if MOXIE worked efficiently, they could land a 100 times larger MOXIE-based instrument on Mars, along with a radioisotope thermoelectric generator.

Over the course of some years the generator would power the system, which would produce up to two kilograms of oxygen per hour, and fill an oxygen reservoir that could be used for breathing or to provide energy for a sample return mission, when NASA astronauts could arrive sometime in the 2030s.

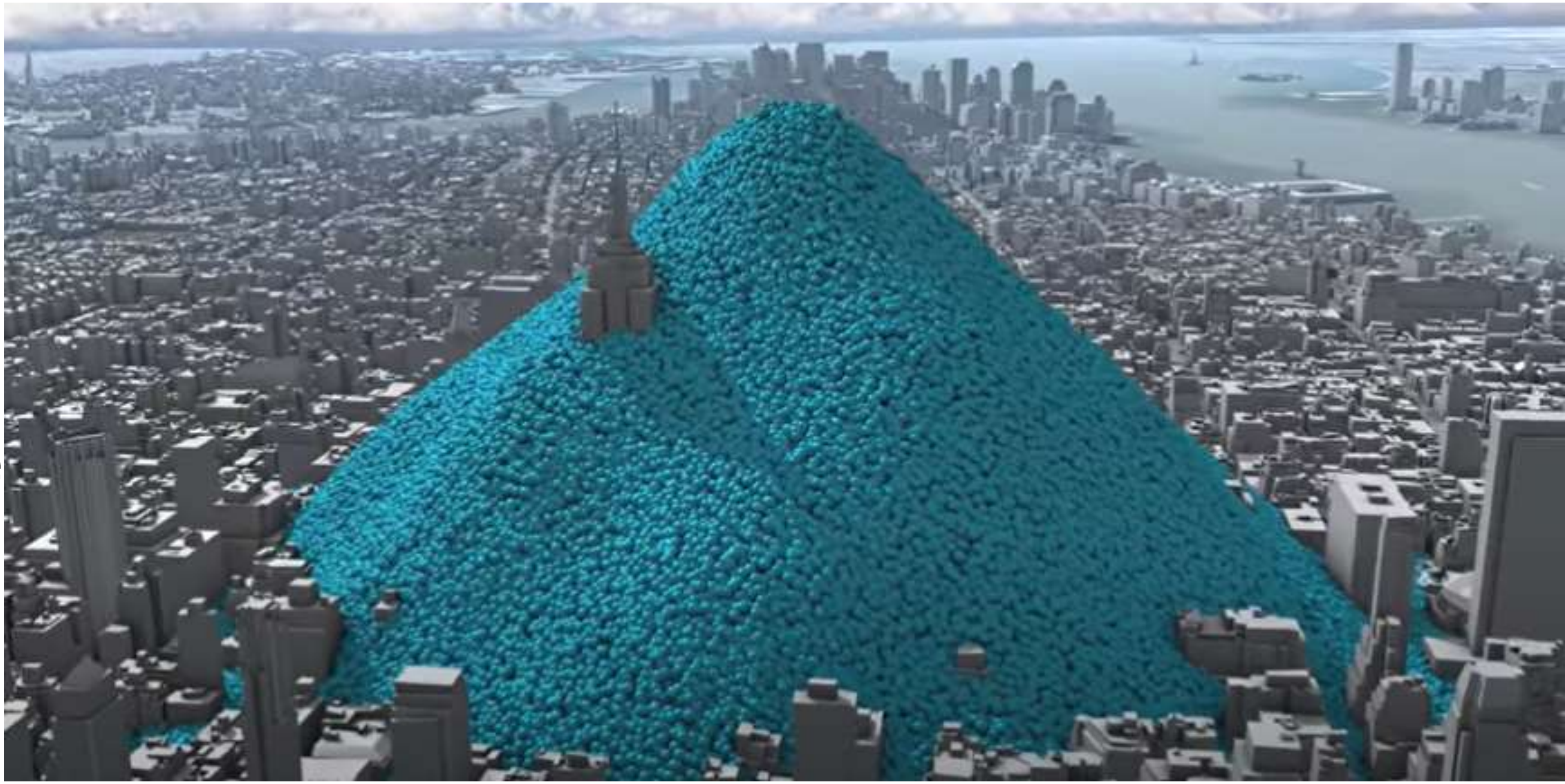


A VISUAL COMPARISON OF HOW MUCH CARBON DIOXIDE IS PRODUCED IN NEW YORK CITY

In 2010 New York City added 54 million metric tons of carbon dioxide to the atmosphere, but that number means little to most people because few of us have a sense of scale for atmospheric pollution.

New York City's greenhouse gas emissions as one-ton spheres of carbon dioxide gas

https://www.youtube.com/watch?v=DtqSIplGXOA



Carbon Dioxide emissions in 1 day

Each sphere is 1 ton of the gas !!

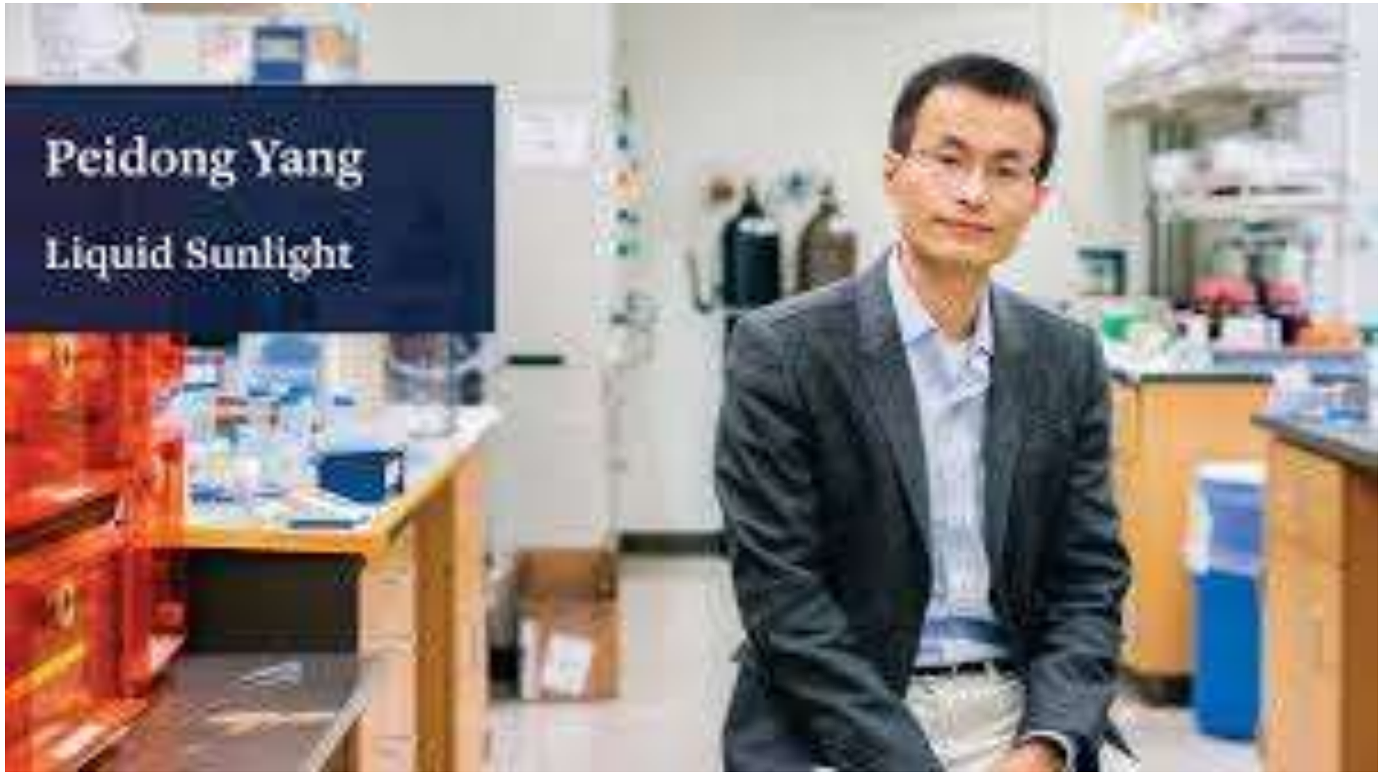
“LIQUID SUNLIGHT”

Peidong Yang and his team have recently reached a milestone – Demonstrating a process in which sunlight shines into a water solution bubbled with carbon dioxide to produce chemical fuels, polymers and, under some conditions, even pharmaceutical intermediates to make drugs.

The prototype system converts solar to chemical energy at a higher efficiency than nature.

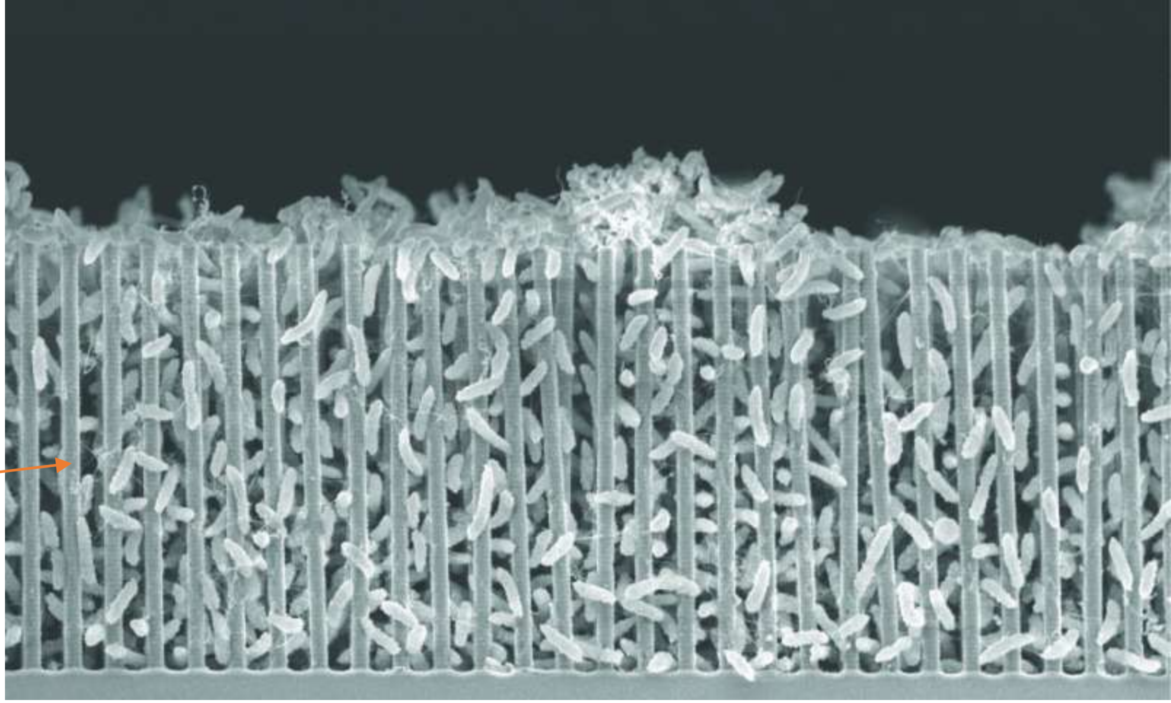
Decades into the future, the same technology could provide fuel and oxygen for the first Martians and could even be tweaked to produce fertilizer.

https://www.youtube.com/watch?reload=9&v=5fPmFGVgtWg&feature=emb_logo 4.2 minutes



HARVESTING SOLAR FUELS THROUGH A BACTERIUM'S UNUSUAL APPETITE FOR GOLD

Dr. Yang and his students placed light-absorbing gold nanoclusters made of 22 gold atoms (Au22) inside a bacterium, creating a system that produces more biofuels like **Acetate - essentially acetic acid, or vinegar,** than previously demonstrated.



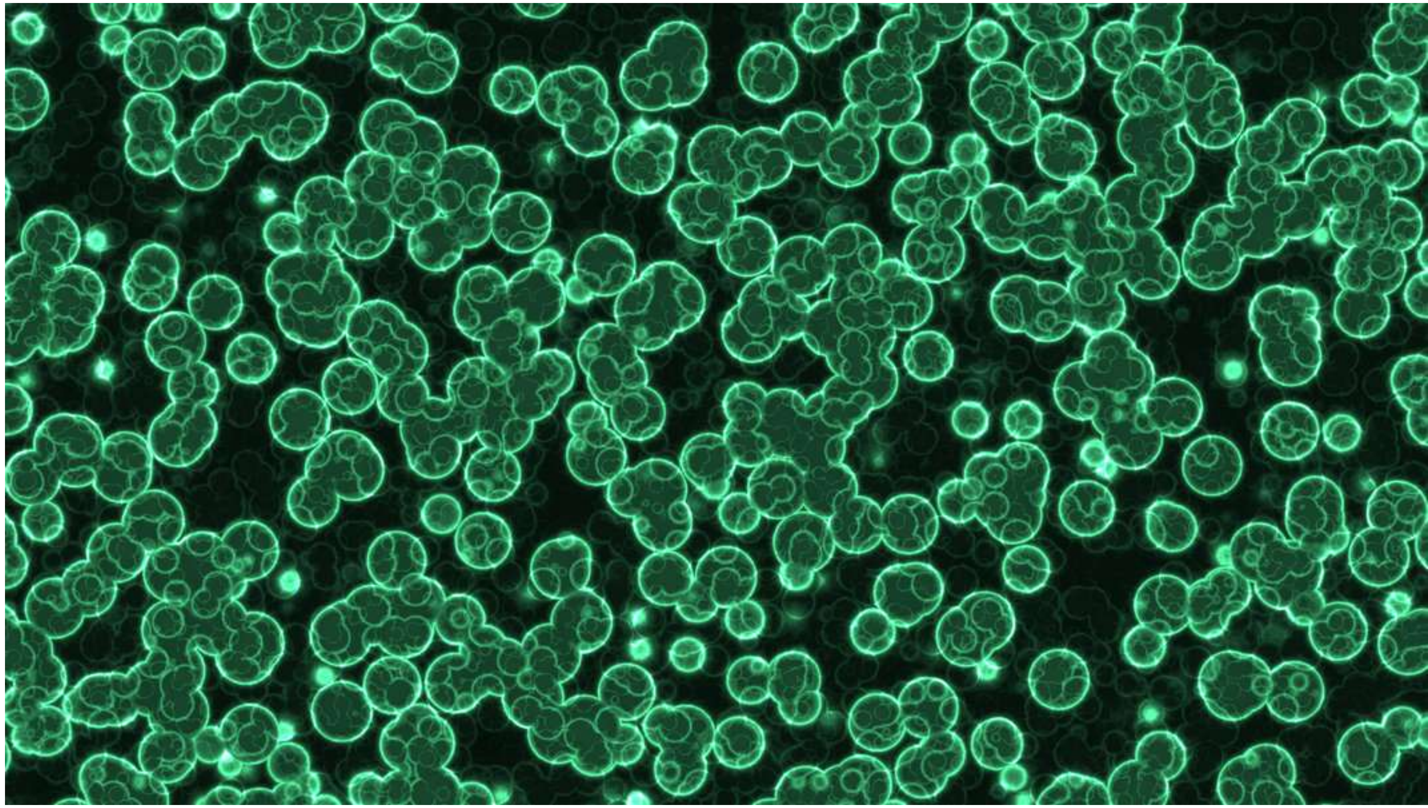
These silicon nanowires are thin silicon wires about one-hundredth the width of a human hair, used as electronic components, and are essentially like an antenna: They capture the solar photon (light particle) just like a solar panel and generate electrons to feed the bacteria.

Then the bacteria absorb CO_2, do the chemistry and spit out acetate.

The oxygen is a side benefit and, on Mars, could replenish colonists' artificial atmosphere, which would mimic Earth's 21% oxygen environment.

A Solar “Foundry” and Greenhouse for growing food on Mars

Cyanobacteria also use photosynthesis to produce energy, but they're able to do so in conditions with far less sunlight than what you need to grow your tomato plants.



In fact, scientists have found cyanobacteria thriving in the deepest trenches in the ocean.

Most plants and organisms convert visible light into energy using chlorophyll-a.

The researchers figured out that **cyanobacteria use a special kind of chlorophyll, chlorophyll-f**, to convert far-red/near infrared light into energy.

This is how they're able to live in such low-light environments.

ARTIFICIAL PHOTOSYNTHESIS GETS BIG BOOST FROM NEW CATALYST

A collaboration between Canadian and Chinese researchers seems to have hit the jackpot.

They found a way to combine nickel, iron, cobalt and phosphorus to work in a neutral pH, which makes running the system considerably easier.

With an impressive 64% electrical-to-chemical power conversion, the team are now record holders with the highest efficiency for artificial photosynthesis systems.

By both capturing carbon emissions and storing energy from solar or wind power, the invention provides a one-two punch in the fight against climate change.

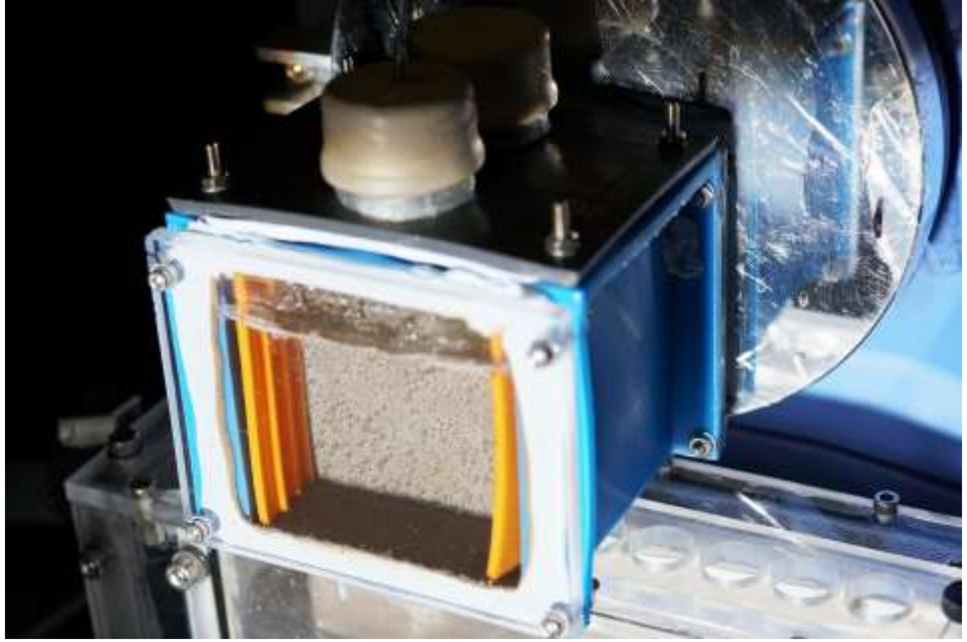
Phil De Luna is one of the lead authors of a new paper published in Nature Chemistry that reports a low-cost, highly efficient catalyst for chemical conversion of water into oxygen.

(Image courtesy of Tyler Irving.)

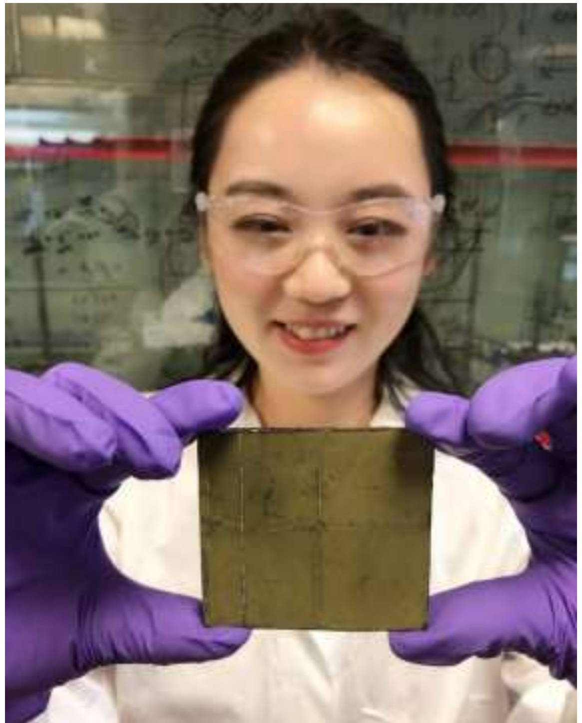
STANDALONE DEVICE CONVERTS SUNLIGHT, CO2 AND WATER INTO CLEAN FUEL

This device, developed by Dr. Qian Wang and her colleagues from the University of Cambridge is based on an advanced ‘photosheet’ technology and converts sunlight, carbon dioxide, and water into oxygen and formic acid — a storable fuel that can be either be used directly or be converted into hydrogen.

Harvesting solar energy to convert carbon dioxide into fuel is a promising way to reduce carbon emissions and transition away from fossil fuels and do it by producing these clean fuels without unwanted by-products, which they were able to do.



Credit: University of Cambridge



ARTIFICIAL PHOTOSYNTHESIS USES SUNLIGHT TO RECYCLE CO2 INTO ‘GREEN METHANE’

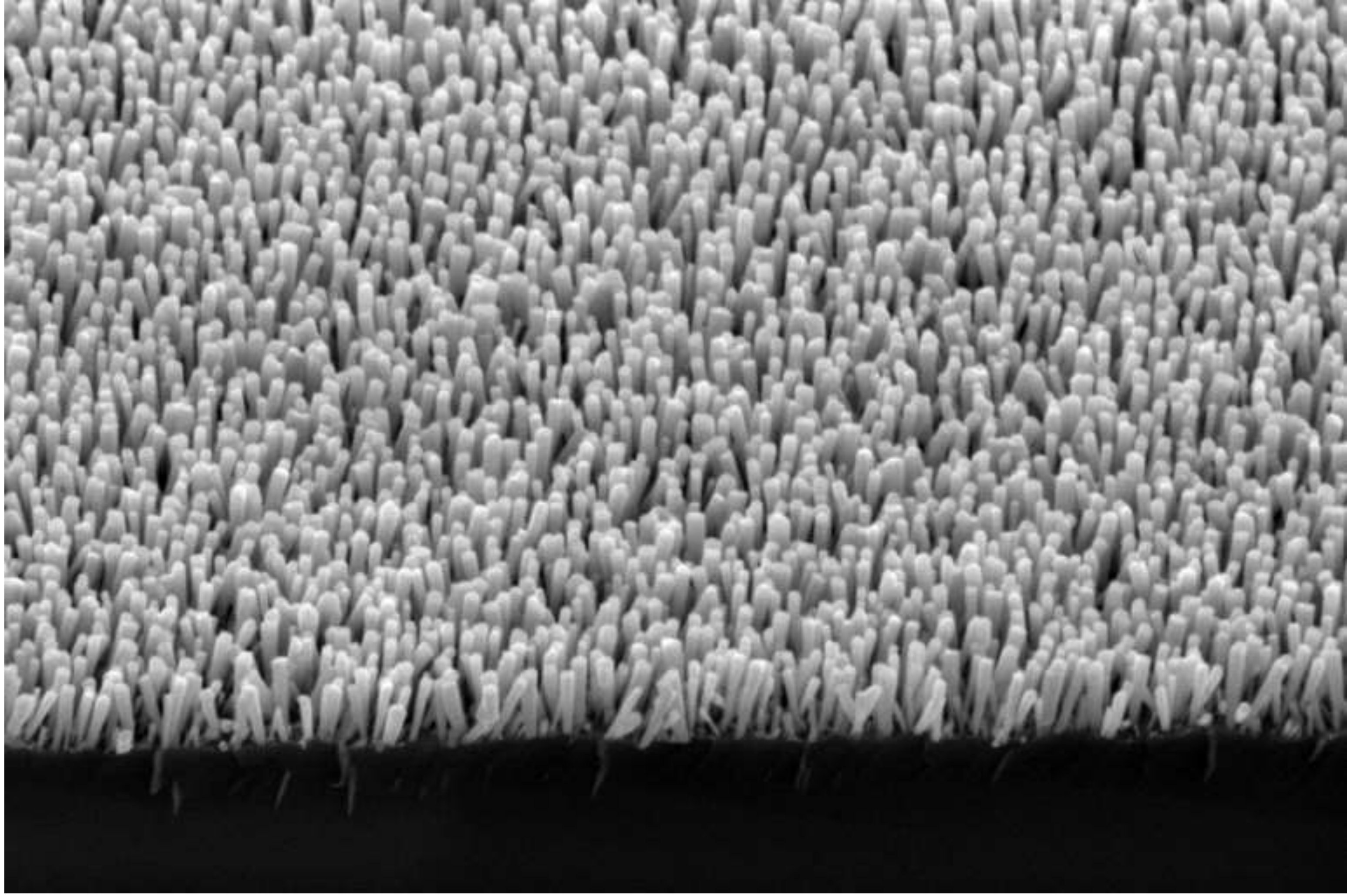
A new artificial photosynthesis approach uses sunlight to turn carbon dioxide into methane, which could help make natural-gas-powered devices carbon neutral.

Methane is the main component of natural gas.

The key catalyst components are nanoparticles of copper and iron.

The base layer is a silicon wafer, like those already in solar panels.

That wafer is topped with nanowires made of the semiconductor gallium nitride.



AN ELECTRON MICROSCOPE IMAGE SHOWS THE SEMICONDUCTOR NANOWIRES.

THESE DELIVER ELECTRONS TO METAL NANOPARTICLES, WHICH TURN CARBON DIOXIDE AND WATER INTO METHANE.

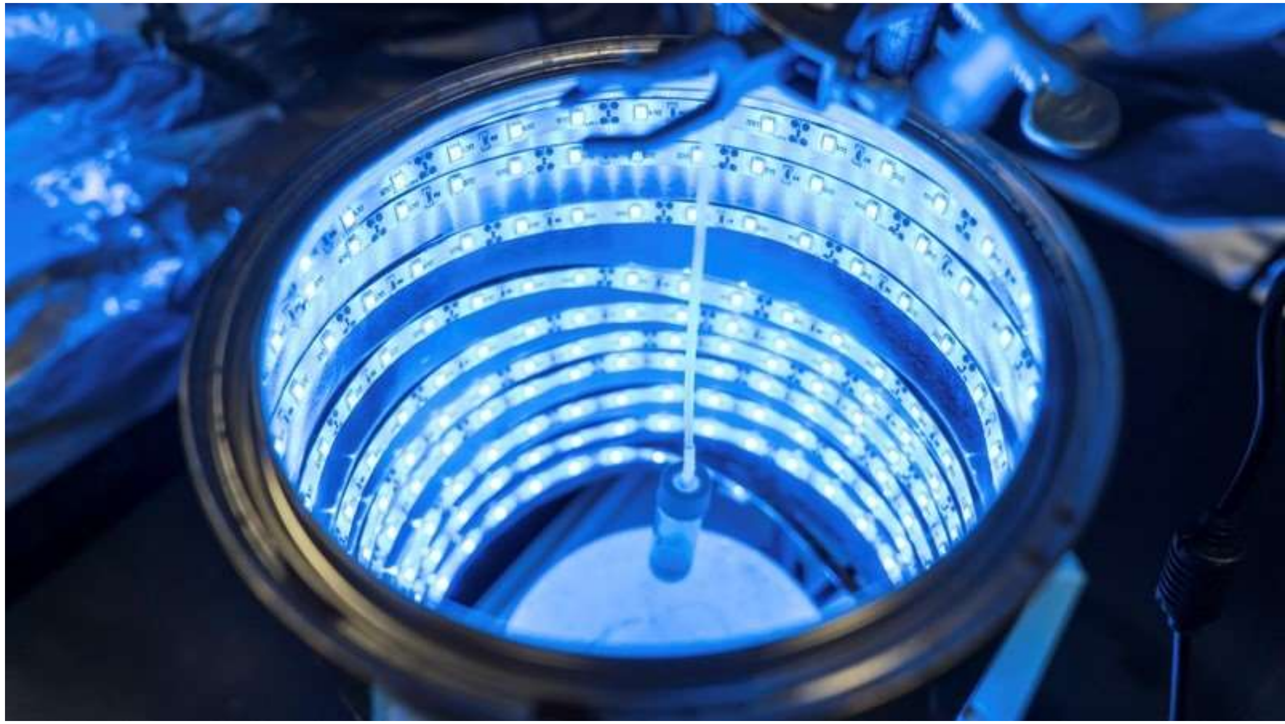
CREDIT: BAOWEN ZHOU

Up to now, scientists working on Artificial Photosynthesis have only succeeded by using expensive materials, such as platinum, rhenium and iridium, or by using titanium dioxide, which is only useful in the presence of ultraviolet light – only a mere 4% of the sunlight.

Fernando Uribe-Romo, an Assistant Professor from University of Central Florida, has announced the development of an artificial photosynthesis triggered by blue light.

By using a synthetic material called metal-organic framework (MOF), made of titanium and an organic molecule that acts as an antenna, He and his students were able to convert CO2 into oxygen and formate and form-amides, two reduced forms of carbon.

2.5 minutes - https://www.youtube.com/watch?v=cdTuwe2SruA&feature=emb_logo



The Cemvita company has been working on a process to convert carbon dioxide (CO_2), into nutrients such as the sugar Glucose (for consumption), pharmaceuticals, as well as chemicals, and polymers, which could be utilized for a settlement on another planet,.

They are testing their CO_2-to-glucose conversion system under microgravity aboard the International Space Station to see how well it works.

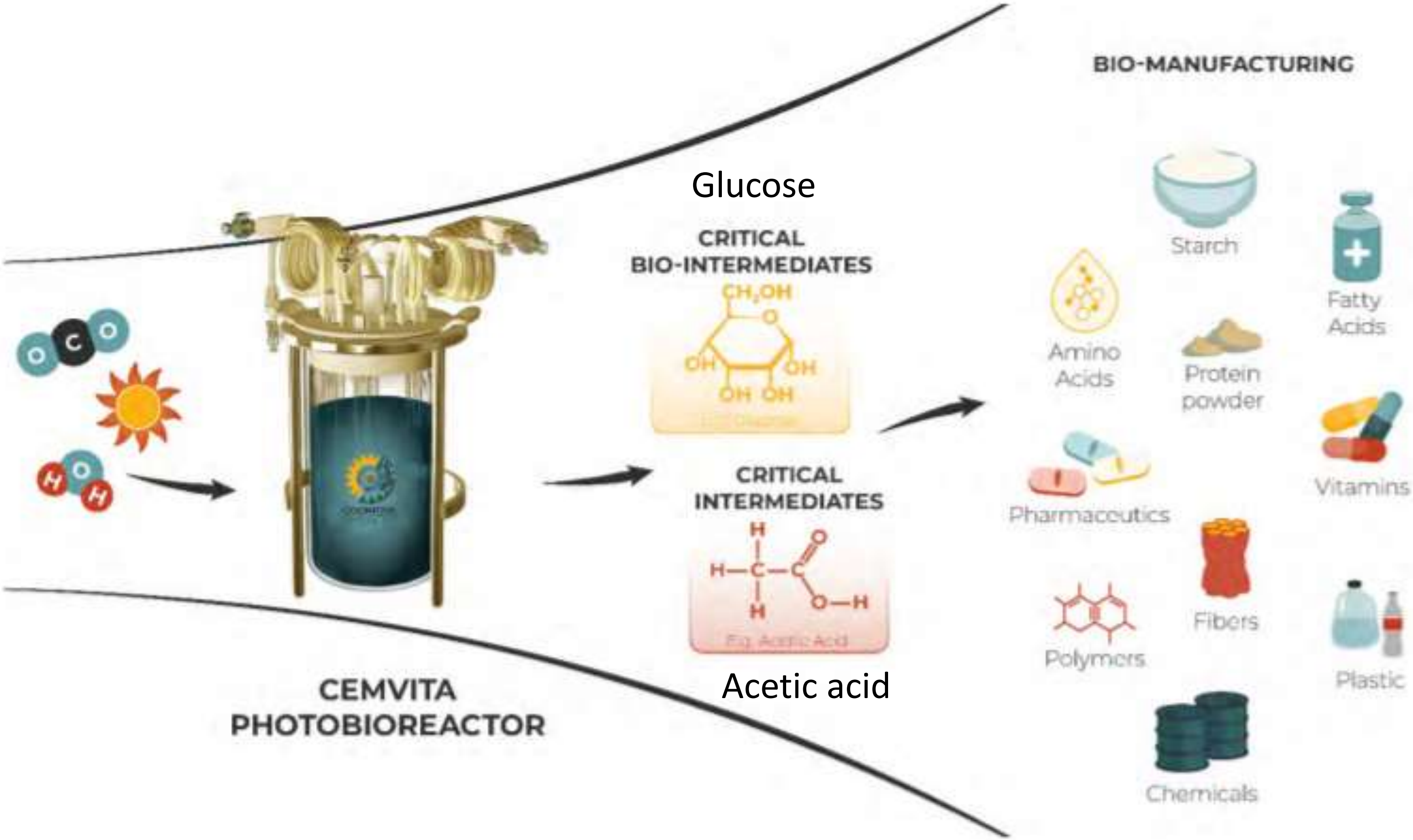


Figure 1. CO2 and water are the main ingredients for production of a variety of resources in space and on Mars

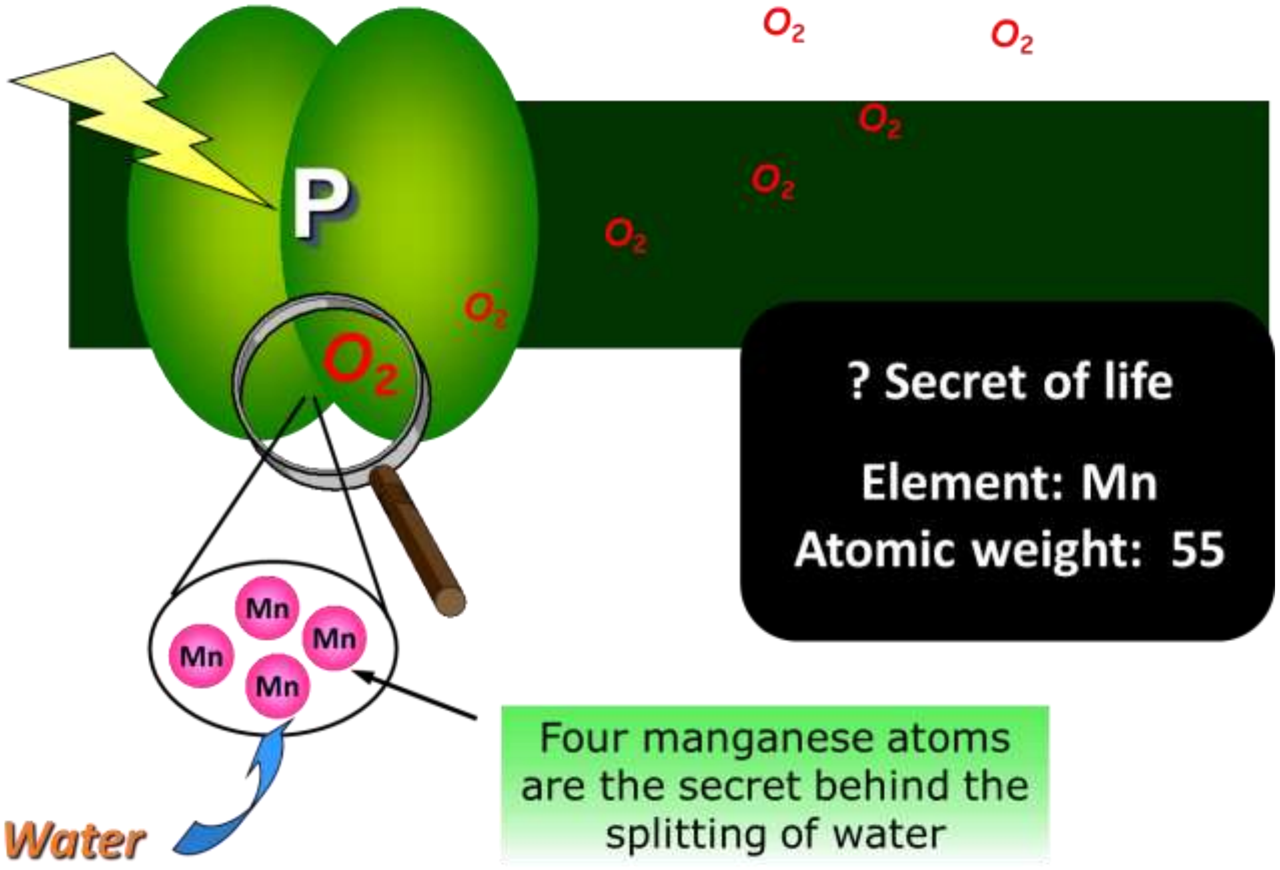
THE END

USING MANGANESE AND A MATRIX LIKE TEFLON FOR THE CATALYST, WATER CAN BE SPLIT INTO HYDROGEN AND OXYGEN

Scientists at the Monash University in Australia found that one of the best material candidates for splitting water are manganese complexes embedded in a Nafion matrix, a Teflon-like polymer.

Their manganese complexes produce nanoparticles of manganese oxides within a Nafion matrix.

When exposed to light, these oxides promote water oxidation, a key and challenging reaction associated with the splitting water into oxygen and hydrogen. The hydrogen can be stored as an energy carrier."



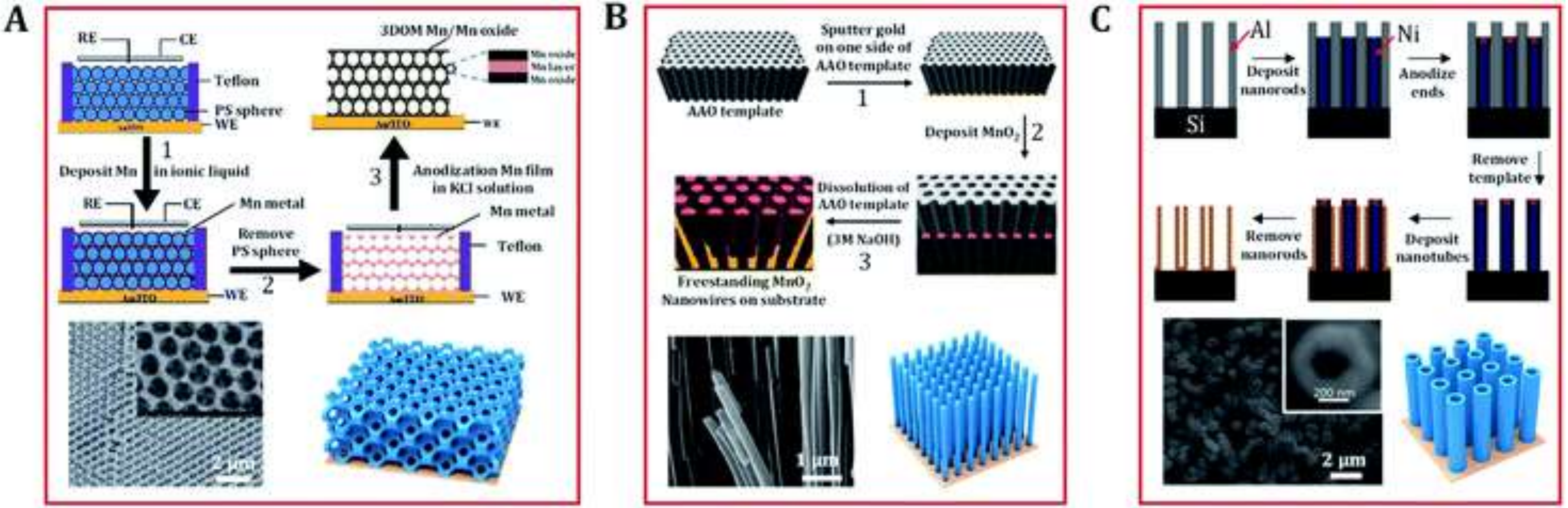
Nafion is a brand name for a fluoropolymer like Teflon and is the first of a class of synthetic polymers with ionic properties that are called ionomers.

Nafion has received a lot of attention as a proton conductor for proton exchange membrane (PEM) fuel cells because of its excellent thermal and mechanical stability.

(A) Scheme of the preparation of a high-porosity 3D ordered macroporous Manganese/Manganese oxide electrode and its related SEM image.

(B) Schematic diagram representing the electrochemical template synthesis of Manganese Oxide nanowires arrays and SEM micrographs of manganese oxide nanowire arrays.

(C) Same as (B) but using nanotubes



3D porous

3D nanowires array

3D nanotubes array

THE END

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Main part of slide 10, courtesy of Jim Rauh

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