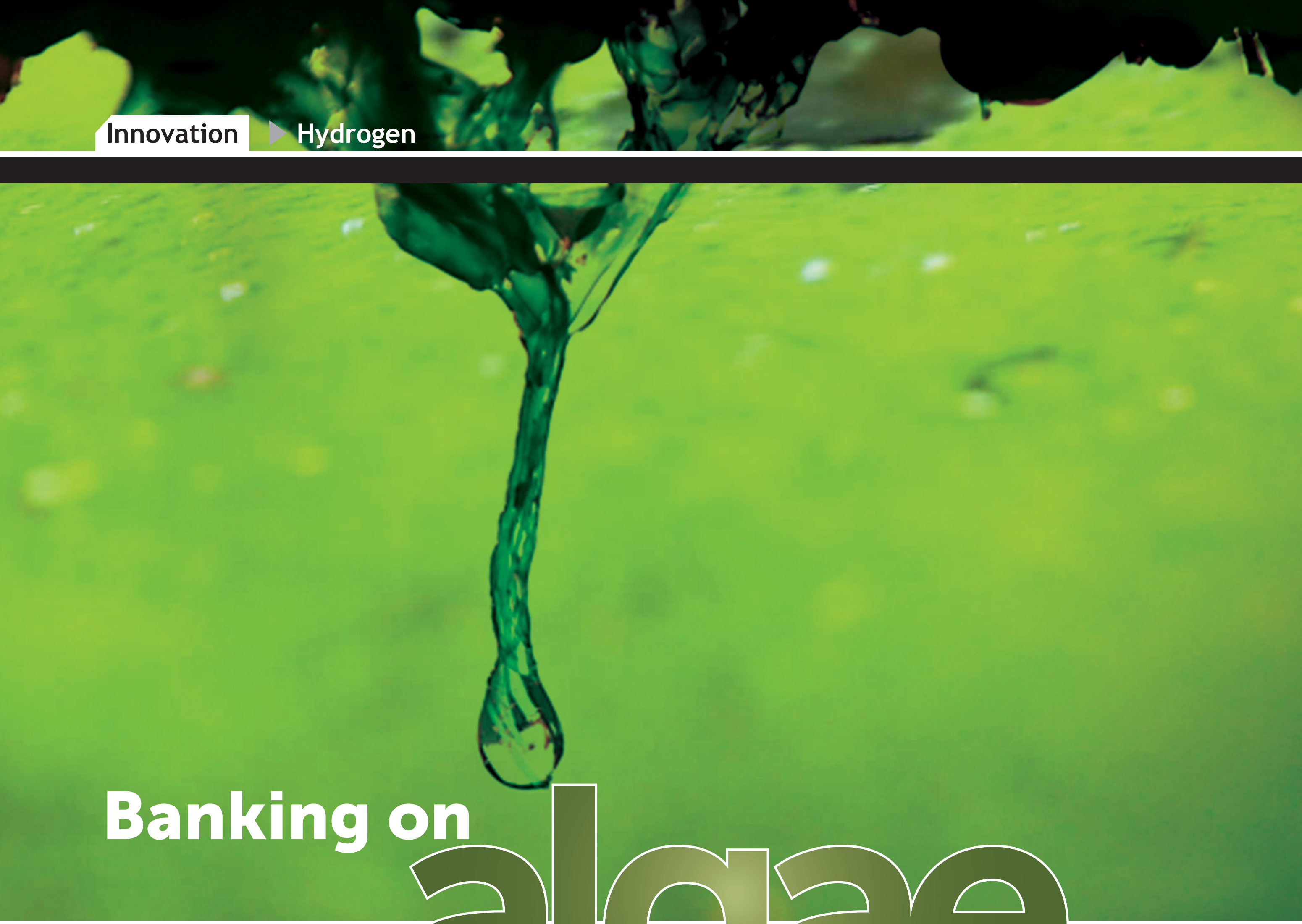


Banking on algae for fuel

Commonly, algae are capable of using energy from sunlight to split water molecules and release hydrogen. However, this approach hasn't yet been harnessed for fuel production since ordinarily, hydrogen production takes a back seat to the production of compounds that the organisms use to support their growth. Now, a recent innovation could change that. **Iftach Yacoby** writes on production of hydrogen using bioengineered microorganisms

The growing demand for energy, combined with excess carbon footprint generated by fossil fuels and conventional biofuels, forces humanity to seek renewable, clean energy alternatives. Hydrogen gas, a real, zero-carbon footprint source of energy, is a promising solution.

One of the most abundant element on Earth, (since each water molecule contains two atoms of hydrogen), it can have widespread uses in the economy, ranging from fuel cells in large electrical plants to mass transportation. Already, fuel cell car models have been presented, and soon, they will be commercially available by major auto makers.

Currently, hydrogen is mass-produced by a non-green method called steam reformation of hydrocarbons. The main renewable method of hydrogen production is electrolysis of water. This process needs a sophisticated metal catalyst such as platinum, which is not affordable by most countries. However, what we are keen on, is to develop a simple, affordable, biological means of hydrogen production.

Two distinct biological processes can produce hydrogen: firstly, fermentation, in which sugars are the energy source to produce hydrogen and secondly, photosynthesis, in which the sun's energy is consumed directly or indirectly to produce hydrogen. Photosynthesis can be considered as one of the most significant process on Earth. For the past 3 billion years, it is has been solely responsible for the shift to and maintenance of oxygen in the atmosphere. It also regulates the Earth's "thermostat" by limiting the greenhouse effect. Moreover, the photosynthetic conversion of carbon dioxide gas to sugars, provides the primary food source on Earth.

> Algal hydrogen production is an important renewable energy alternative that could be integrated in developing countries

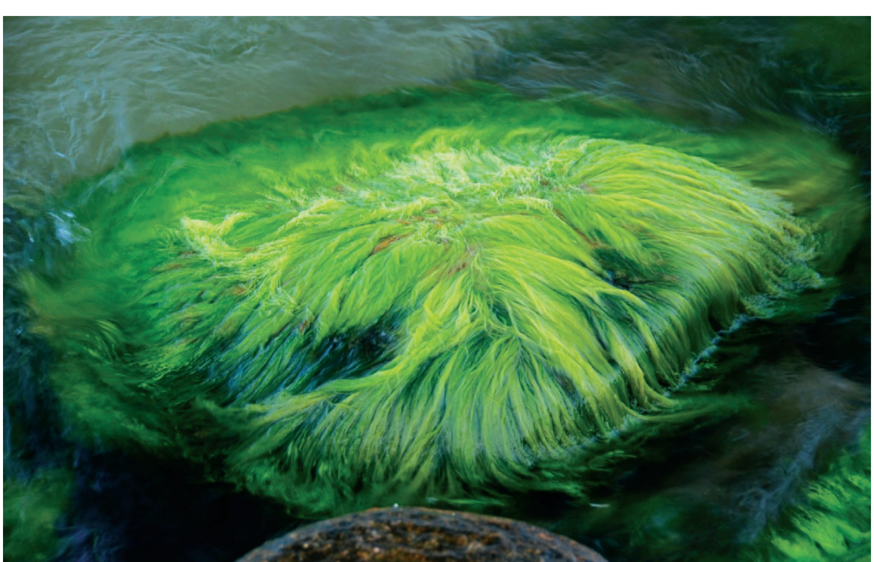
Photosynthetic organisms comprise a vast kingdom of many evolutionary levels, ranging from microbial organisms to multicellular plants. Only a minor subset of microorganisms, specifically cyanobacteria and microalgae, can produce hydrogen gas. However, this process functions as a survival mechanism, and is normally limited to very specific stressful physiological situations.

A common feature of all hydrogen-producing organisms is the ability to synthesise a special nanocatalyst, the hydrogenase enzyme. This enzyme is as efficient as pure platinum, and consists of anorgano-metallic core coordinated with esoteric ligands like carbon monoxide or cyanide. This makes it an attractive potential renewable energy source. However, in order to be useful as a hydrogen production source, it must be coupled to photosynthetic processes. Unfortunately, it is extremely sensitive to oxygen, and only a few seconds of exposure are enough to completely and irreversibly inactivate it. The combination of oxygen-producing photosynthesis, together with the oxygen-sensitive process of hydrogen production, is problematic and unlikely to occur efficiently in nature.

In recent years, researchers Melis, Seibert, Ghirardi and their co-workers at UC-Berkeley and National Renewable Laboratory (NREL), found that sulphur starvation of the algae could partially solve the oxygen problem. High-rate and continuous hydrogen production was observed for several days, with a light-to-hydrogen conversion ratio up to 2 per cent of the maximal theoretical 10 per cent. However, a conversion ratio of at least 5 per cent is needed to make the process economically viable.

Our goal is to study and manipulate photosynthesis in order to make high-rate hydrogen production economically feasible. Also, we want to generate a basic understanding of the key junction where most of sun's energy is shuttled to the competing processes of sugar production.

We believe we have found the main point at which sugar production takes over the competing process. Using purified cellular components, we build the necessary biological processes in test tubes. Our experiments have shown that physical localisation of the first component of the sugar production machinery at the photosynthetic complex makes it "the first in line" to receive photosynthetic energy. We also found that about 90 per cent of the energy is lost to sugar production. Even when the concentrations of different natural components are varied, 90 per cent of the energy is consistently



Pic: Patrick Gillooly

Postdoctoral researcher Iftach Yacoby holds vials containing two of the materials used in the research: On the right, green photosynthetic membranes derived from plants, and on the left, brown ferredoxin protein, one of two enzymes the team combined to increase hydrogen production.

delivered to sugar production under an oxygen-free environment.

The experiment

A process capable of bypassing this sensitive junction pointin-vitro, was bioengineered. Also, the fact that all outgoing energy transfers from photosynthetic machinery are solely mediated by Ferredoxin, a small metal-containing protein, was exploited. A physical fusion of the energy messenger component (Ferredoxin) with the hydrogen producing catalyst (Hydrogenase) was the key to solving the problem. The physical proximity of the two proteins during photosynthesis would result in immediate energy transfer from Ferredoxin to Hydrogenase, which could then be used for hydrogen production.

Our experiments show that the fusion protein can be used for efficient hydrogen production. First, we showed that is possible for energy to be transferred directly from isolated photosynthetic machinery to the fusion protein. This transfer was so successful that the hydrogen production rate was ten-fold more efficient than that of the natural non-engineered hydrogenase. We then proceeded to doing vitro experiments. Whole plant or algae cells were physically broken and mixed with the fusion protein to

test whether it could compete with other processes, including sugar production. The fusion performs very well. Indeed, a 400 per cent increase in hydrogen production was observed when compared to that of the natural Hydrogenase.

The next step towards developing a viable renewable energy system is to generate genetically modified algae which can efficiently express the fusion protein. Algae strains that can produce hydrogen with an energy conversion ratio grater than 5 per cent would be economically viable. This process could be achieved in three to five years with appropriate funding and manpower.

Algal hydrogen production is an important renewable energy alternative that could be easily integrated in developing countries since water and the simple salts needed for growing algae are affordable. Moreover, there's minimal usage of precious fertile land, as algae can be grown in tanks, bioreactors, and even in the sea. Several groups around the world are developing mass algae bioreactors, but we believe that an efficient algal strain is the prerequisite to success. If our method succeeds, we will be able to offer an affordable and simple renewable energy system. en

A receiver of the Yang Trust fellowship, Iftach is currently a European Microbiology Organization (EMBO) post-doctoral fellow at the lab of Dr Shuguang Zhang at Department of Biomedical Engineering, MIT. With a M.Sc and Ph.D in biotechnology from Tel Aviv University, his interests include the study and development of affordable biological renewable energy sources.

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