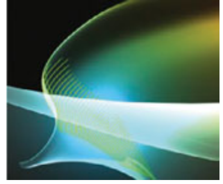
MRS Energy & Sustainability
page 1 of 9

doi:10.1557/mre.2020.27



PERSPECTIVE

Sustainable integration of human activities into the global ecosystem

Philippe Lorge, H2WIN S.A. Rue du gendarme, N°4, Nivelles B-1400, Belgium*

Address all correspondence to Philippe Lorge at dr.philippe.lorge@h2win.com

* *H2WIN* – *H*ydrogen to *W*orldwide *IN*tegration – is a private company developing a hydrogen bio-generator: H2GREEN – *H2 G*eneration by *RE*newable *EN*ergy – which, for a low investment cost, will enable hydrogen to be produced locally with a high yield from water and light (sun or electrical) thanks to an enzymatic system inspired by nature (Biomimicry). The author is a collaborator of the University of Liège not as an independent academic scientist, but a private-sector entrepreneur.

(Received 26 May 2020; accepted 16 July 2020)

ABSTRACT

The sustainable integration of human activities into the global ecosystem is discussed, pointing out fatal anthropogenic heat as a major ecological problem and proposing global technical and economical solutions.

For human sake, we must get out of the "thermal age" and implement the "electroprotonic era" as soon as possible. Contrary to thermal power, electroprotonic is sustainable and can be produced by photoenzymatic systems, a cheap way to produce hydrogen (H_2) or ammonia (NH_3). We can accelerate the advent of this new era if we re-integrate external costs generated by thermal energies into their final prices. The author is leading the H2GREEN project in Belgium as an entrepreneur for more than a decade, which develops the photoenzymatic production of dihydrogen from water. The aim of the H2GREEN project is to contribute to the launch of a low-cost, renewable Hydrogen-based local economy as an energy carrier. Among the difficulties of this launch, the most important is certainly the lack of competitiveness due to the unfair competition of carbon products that externalizes their costs (CO_2, oil spills, lethal pollution, armed conflicts, political oppression, foreign dependence, etc.).

DISCUSSION POINTS

- *Ecological problems:* Countless deteriorations in our ecosystem are caused by human activity causing premature deaths, social instability, immigration, or wars that are the premises of our hard-living conditions in a few decades from now. A very simple experiment "earth on the rocks" ease to realize the major consequences of the fatal heat emitted by human activities and transmitted to the oceans by convection and irradiation through the lower layers of the atmosphere.
- *Technological strategy:* Transition from "thermal age" (combustion or nuclear) to "electroprotonic era" using energy and chemical vectors that limits thermal emissions in low atmosphere and air pollution is the strategy proposed to significantly smooth human ecosystem impact.
- *Technical solutions:* Extensive use of molecular biomimicry through the integration of Mother Nature tools like enzymes into engineering systems has a huge potential. In particular, the use of redox enzymes inspired by photosynthesis in electrochemical devices for the production of energy vectors, ammonia, or carbohydrates from water and air by using solar light. Thanks to new bioinspired catalytical materials we are at the eve of a new industrial revolution.
- *Socio-economic solution:* Market economy laws must be respected by integrating externalized costs into prices. This will make companies responsible for the impact of their activities and will lead to fair competition between electroprotonic sustainable energies and the thermal source of energy.

Keywords: biomimetic (chemical reaction); economics; energy storage; environmentally protective; society

Ecological problems

Countless deteriorations in our ecosystem are caused by human activity causing premature deaths, social instability, immigration, or wars are the premises of our living conditions in hell in a few years.

It is now known that some pollution has disastrous effects:

- Infrared light and convection heat from combustion and nuclear power transmitted to the oceans through the lower atmosphere, increasing their temperature/volume/level, causing ice melting.
- Carbon dioxide, a greenhouse gas that once dissolved in the oceans, causes acidification/anoxy and warms the earth.
- Nitrogen oxide, from fertilizers reacting with O_2, destroys the ozone layer that protects the earth from UV.
- Polycyclic aromatic hydrocarbons, emitted by combustion, cause cancers.
- Nitrogen oxides, emitted by combustion, are the cause of heart, pulmonary, and cerebral diseases caused by atherosclerosis and thrombosis.

Among these degradations, there is one well known to scientists but poorly understood by the general public: the role as a climate buffer of polar caps. The melting of aqueous ice is a very energy consuming phenomenon, the melting enthalpy of the ice (334 kJ/kg at 0 °C) makes it possible to heat water from 0 to 80 °C. Without embarking on an analytical reasoning of thermodynamics to which only physicists are sensitive, we propose a simple empirical experience within the reach of everyone in their kitchen, which allows a very effective perception of the importance of what we are living with the melting of ice floes, sometimes several million years old.

Experience "Earth on the rocks"

Protocol

A beaker filled with ice-covered water (see Fig. 1) is heated at low constant power, the water temperature is measured over time (see Fig. 1).

We observed that as long as the ice surface is complete, the water temperature is pretty stable since the energy exchange area between water and ice is constant and sufficient to absorb heat with the ice/water phase change. When ice melted holes appear, a first kinetic of increasing water temperature occurs over time. Probably, the exchange surface has decreased and is no longer sufficient to absorb the additional energy. Once the ice has melted, the rate of temperature raised even more: all additional energy increased the water temperature, there was no ice to melt anymore.

The analogy of the results of our experience is striking with the pattern of the increase in Earth's temperature compare to late 19th Century which seems to accelerate (Fig. 2) in parallel with the disappearance of the boreal ice floe (Fig. 3).

This experiment makes it possible to realize the major consequences of the fatal heat emitted by human activities transmitted to the oceans in the form of convection and irradiation through the lower layers of the atmosphere. Of course, the earth is in a metastable thermodynamic stage with retroactives systems like albedo that are much more complex than a beaker in a kitchen ... but it is now clear that Arctic ice floe will disappear in the summer before 2050.[1]

Technological strategy

The latest IPCC report[2] highlights the importance of the release of anthropogenic heat into the lower layers of the atmosphere, transmitted to the oceans, it causes serious climatic disturbances. One thing is to limit greenhouse gases, the other is to limit supplying heat to this greenhouse. It is, therefore, essential and urgent to leave the "thermal age" which generates energy through heat using combustion or nuclear processes to enter the "electroprotonic era" where electrical energy can be directly produced by fuel cells emitting significantly less heat.

Taking into account the low-efficiency conversion of energy to yield of nuclear power (around 33%) and fossil combustion (around 40%) to produce thermal electricity and even lower in thermal engines (around 30%), compared to fuel cells (around 66%), we can estimate that about two-third of the energy produced by humanity is dissipated and warms the lower atmosphere and the oceans. The transition from the "thermal age" to the "electroprotonic era" is the solution to significantly reduce the fatal heat emitted by human activity from two-third to one-third.

The use of hydrogen, or its carrier, is a major component of this solution: hydrides, ammonia, liquid polymers – LOHC (Liquid Organic Hydrogen Carrier), etc ... , as clean energy vector and for which security issues are managed since decades.

"Hydrogen economy" will see at short term[3] the use of hydrogen as a storable, ultra-ecological fuel that can be used to produce electrical energy avoiding thermal conversion (combustion or nuclear). The ecological nature of hydrogen is undeniable when it is produced from water and clean renewable energy. In this case, given that the use produces only water, the green hydrogen economy is based on a water to water cycle perfectly integrated into our planet's ecosystem.

Unfortunately, more than 99% of hydrogen is currently produced from fossil energy (gas and coal) or nonrenewable energy (electrolysis using electricity from gasoil, coal, gas, or nuclear).

Technical solutions

Sensitized to the potential of the H_2 economy at the World Summit in Rio 1992 with the presentation of the MAZDA HR-X, the author has been leading since 2009 the project H2GREEN to develop a photoenzymatic hydrogen generator from water based on the biomimetics of photosynthesis. A solution that has existed for billions of years and is a water-to-water cycle since the conversion of H_2 into electricity reproduces water.

The global use of hydrogen from water can rise legitim concerns about freshwater shortage, nevertheless, some precise information shows the relative absence of water problem generated by H_2 economy:

1. Quantity of water: 1 kg H_2 provides about 3 days of electrical consumption for a common Belgian family, to produce this kg of H_2 we need 9 l of water representing only about 2% of its tap water consumption.

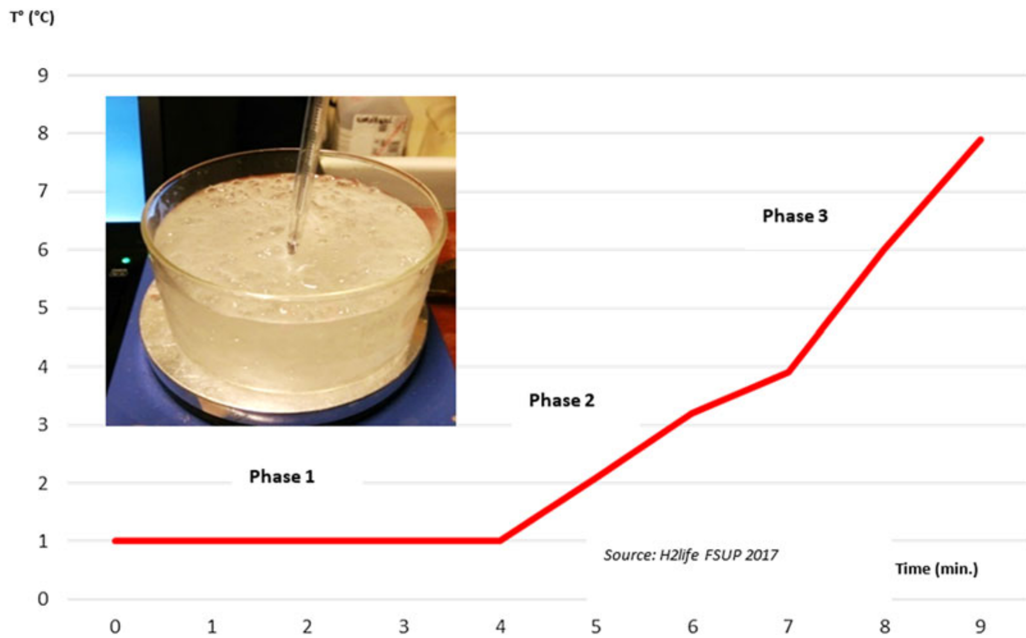


Figure 1. Heat water + ice: Water T° over the time. Source: H2life Foundation.

2. When H_2 is converted to electricity, it reproduces water that can be condensed to recover additional energy and pure water.
3. In the case of enzymolyse, no pure water is needed, sea water is not a problem like with platinum catalyzers, for instance.

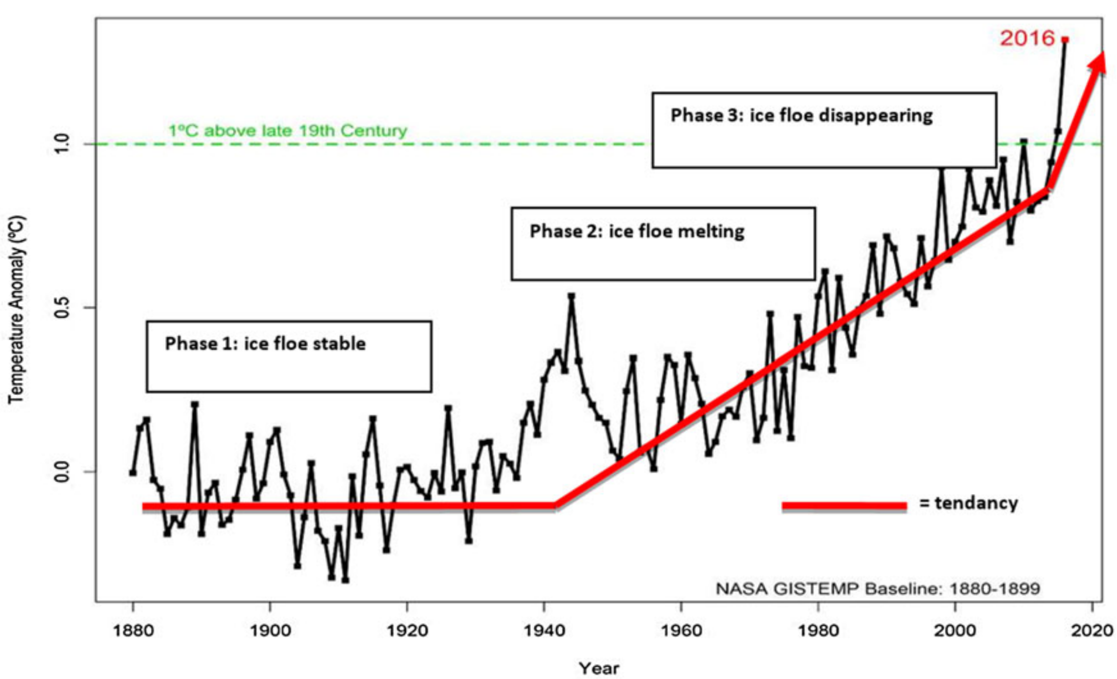


Figure 2. Mean Earth T° from 1880 to 2016. Source: NASA GISTEMP.

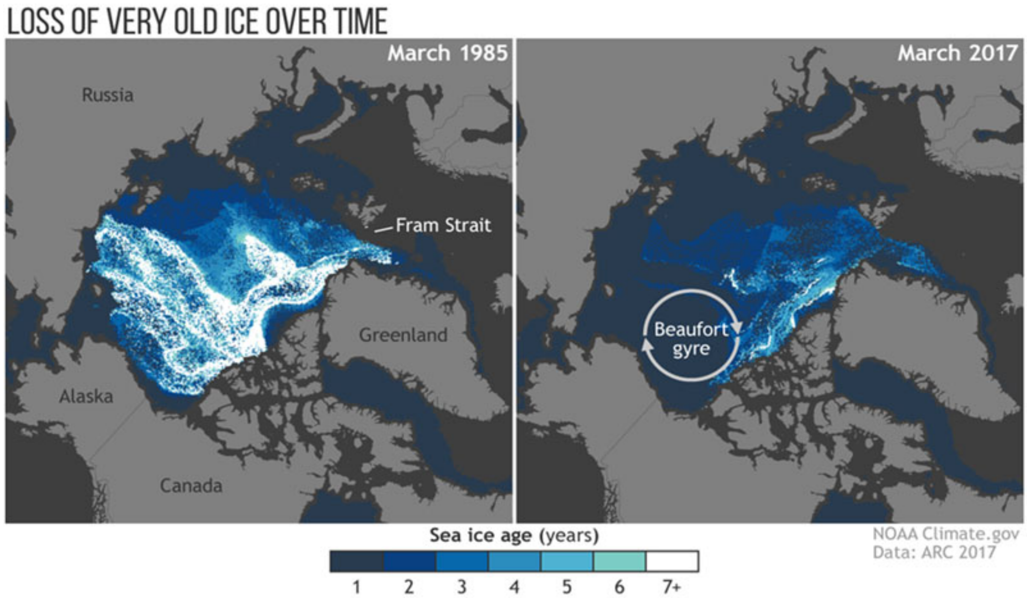


Figure 3. The vanishing Arctic perennial ice floes between 1985 and 2017. Source: NOAA Climate.gov.

What do we mean by "molecular biomimicry"?

Biomimicry, in general, consists of imitating or drawing inspiration from the solutions developed by biological evolution and implementing them at the level of human engineering: the fins of Jubarte whales have inspired the shape of aircraft wings that minimize turbulences, this is a macroscopic application.

Molecular Biomimicry, in particular, makes it possible to draw inspiration from the tools (enzymes) or molecular configurations of biological systems to develop highly efficient and sustainable engineering systems. Applications are then made at the nanometric level (nanotechnology).

In this paper, we will discuss the potential of molecular biomimicry in the first stage of water oxidation-related photosynthesis.

Photosynthesis: Efficiency of conversion of light energy to electrical energy

The first step of photosynthesis is described by the Kok cycle[4]: the oxidation of water by the Oxygen Evolving Complex (OEC) of Photosystem II (PSII), also known as the water-splitting complex, involved in the photo-oxidation of water during the light reactions of photosynthesis. This reaction can be simplified by the following reaction if the whole cycle is taken into account:

$$2H_2O + 4\,\text{photons} \rightarrow O_2 + 4\,\text{protons} + 4\,\text{electrons}.$$

The 4 photons are absorbed successively by the chlorophylls of PSII. They can have various levels of energy in the visible domain. Thanks to the cascade energy transfers between pigments, the absorption of each photon causes the photosystem's reaction center (RC) to be excited, it gains an amount of energy equivalent to a photon of 680 nm. This results in a separation of charges between the chlorophyll from the reaction center and an electron acceptor. To extract 4 electrons from 2 water molecules, 4 successive charge separations must occur in the core of the PSII. The accumulation of positive charges allows the oxidation of the OEC. Electrons are transmitted to successive acceptors of PSII by a tunnel effect.[5] When an electron is at the pheophytin level, its potential is about 1.8 V more negative than at the beginning in the OEC.[6,7]

Finally, considering only the energy conversion at the heart of the PSII, 4 photons at 680 nm produce 4 electrons at 1.8 V (Fig. 4).

A trivial calculation allows us to note that the energy efficiency of this conversion is close to 100%.

Energy of 4 photons at 680 nm:

- Energy (J) = $E = h\mu$
- h = Planck constant (6.63×10^{-34} Js)
- μ = Light frequency at 680 nm = light speed (3×10^{8} m/s) divided by the wavelength (6.8×10^{-7} m)
  - 4 photons at 680 nm = $4 \times (6.63 \times 10^{-34} \times 4.41 \times 10^{14})$ = 1.17×10^{-18} J

Energy of 4 electrons at 1.8 V:

- Power (W) = $W = AV$ and $E = Wt$.
- Intensity (A) = A = electron charge = 1.6×10^{-19} C (As)
- Potential (V) = V = 1.8 V
- Time (s) = t = 1 s
  - 4 electrons at 1.8 V = $4 \times (1.6 \times 10^{-19} \times 1.8) = 1.15 \times 10^{-18}$ J

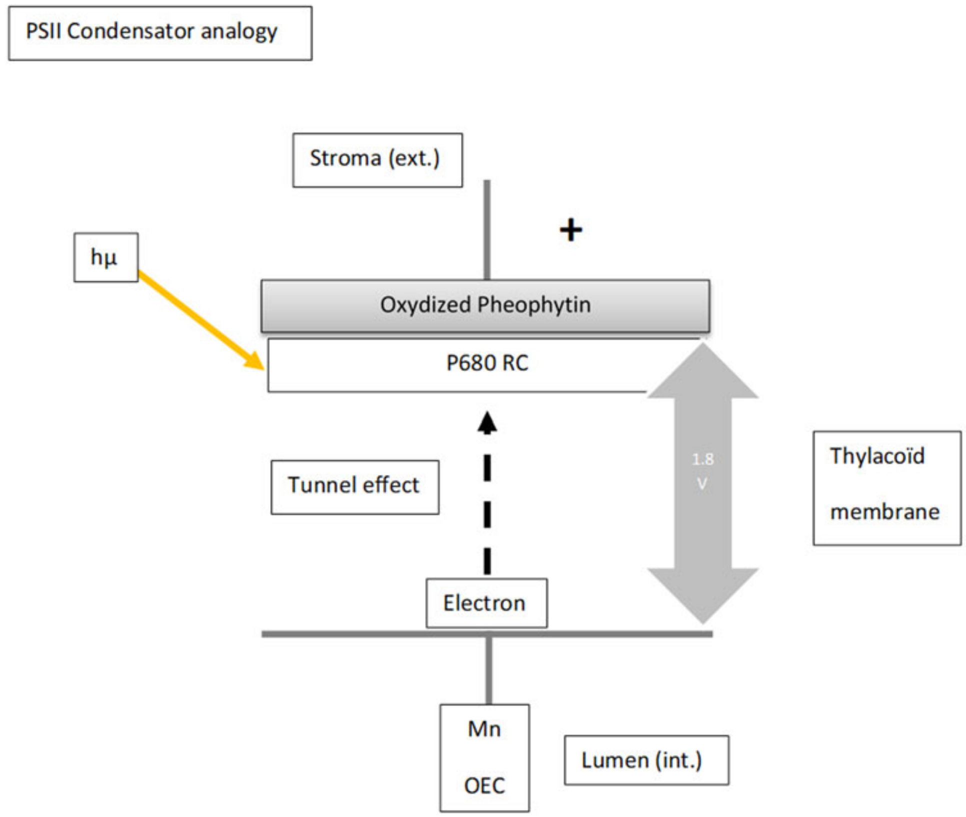


Figure 4. Simplified analogy between the core of the PSII and a polarized capacitor. Source: H2WIN S.A.

PSII conversion light to electricity energy yield = $1.17 \times 10^{-18}/1.15 \times 10^{-18}$ = 98.3%.

Remarks:

1. This is the energy efficiency of the first stage of photosynthesis completed by PSII: the oxidation of water by the conversion of light energy into electrical energy is far from the efficiency of the complete photosynthesis[8] (about 3%) which includes many additional steps to lead to the production of carbohydrates and involve the metabolism of the organism.
2. Energy losses corresponding to internal chlorophyll conversion processes when they absorb photons that are more energetic than 680 nm and recombination of positive and negative charges that can occur, are not taken into account here.
3. Continuous sunlight is not adapted to the discontinuous Kok cycle,[4] a significant part of light energy is lost in the form of heat or fluorescence. Pulsed modulation of incident light reduces these losses and significantly increases energy efficiency.[9]

The above theoretical calculation is, therefore, too optimistic as the empirical measurement is giving a quantic yield of 83%.[10] However, the molecular biomimicry approach consisting of emancipating from biological metabolism/structures and its energy losses by developing core-enzymes[11] suggests an exceptional result in terms of energy efficiency compared to the total photosynthesis yield of around 3%[8] which explains the low yield of biofuels and their nonsense.

Implementation of the use of PSII

Figure 5 describes some examples of applications under development that use photoenzymatic production by the PSII of protons and electricity from water, such as the production of electricity from sunlight, the production of H_2, NH_3, or the production of carbohydrates.

Enzyme reversibility is also an asset for the manufacture of enzymatic fuel cells such as E-FCH (fuel cell hydrogen) or E-FCA (fuel cell ammonia) in similar molecular configurations.

Industrial applications of molecular biomimicry

In our project, we develop an approach[11] to produce by genetical engineering modified core-enzymes consisting to emancipate the technology from as many elements of the native structure as possible, like biological intermediaries and reaction patterns that are dispensable in a technological configuration, such as

- Metabolism;
- Structures and configurations related to this metabolism;

- Structures specific to the in vivo functioning of enzymes;
- Redox centers in enzyme structure; and
- Electronic mediators.

The immobilization of redox core-enzymes on an electrode that directly supplies or collects electrons allows the system to avoid the use of electronic mediators that are essential in a biological configuration in vivo. Similarly, the simplified reaction patterns that directly lead to targeted chemical species avoid significant metabolic losses that reduce in vivo yields.

Industrial enzymology advantages compared to the chemical existing process are significant even if some disadvantages of the technology has to be solved:

Advantages	Disadvantages
High capacity	Low stability
High energy yield	High technical sophistication
High specificity	High number of parameters
Low cost	
Renewable production	
Low criticality	
Genetical engineering optimization	
Sophisticated catalyzers materials produced by fermentation	
Room temperature catalyze	
Local and small-scale systems	
Low pollution	

Socio-economic solution

The author has been leading the H2GREEN project in Belgium for more than a decade, which develops the photoenzymatic production of dihydrogen from water. The aim of the H2GREEN project is to contribute to the launch of a low-cost, renewable hydrogen-based economy as an energy carrier. Among the difficulties of this launch, the most important is certainly the lack of competitiveness due to the unfair competition of carbon products that externalizes their costs (CO_2, oil spills, lethal pollution, armed conflicts, political oppression, foreign dependence, etc.).

We will, therefore, discuss in the last part of the article the problems and consequences of the current noncompliance with the laws of the market economy,[12–14] in particular rules on fair competition or anti-dumping.

First of all, for the sake of clarity, it seems appropriate to define what we mean by the "market economy" given the countless definitions and other existing comments.

The market economy: Freedom and respect for the rules

The most common terms related to the concept of "market economy" are trade, competition, profit, supply versus demand. We, therefore, mean by market economy all industrial, commercial, or service approaches leading to profit in a competitive environment linked to supply and demand free of constraints. However, a free market opposite a market planned and regulated by the state is nevertheless subject to operating rules and laws.

We note among this the anti-dumping and anti-trust laws, both in its own way prevent the "free market" from distortion that artificially favor a company (price agreement between competitors, absence of taxes on fuel or airline tickets, pollution in a developing country, etc.).

Capitalism, on the other hand, can be seen as a consequence of the market economy where profits are exploited for the benefit of private property.

Respect for the market economy = social market economy

The application of the existing laws of fair competition through a simple and transparent but an ambitious and universal system makes it possible to solve many of today's social problems such as the degradation of the climate and the environment by the economy of carbon. The approach that has been under way since 1997 with the introduction of the gas emission exchange system (ETS for Emission Trading System)[15] is in this direction: Emission allowances are established and allocated to each polluter.[16] Then, a free market is set up for the exchange and valuation of these certificates.

While the idea is attractive, its application is very laborious and has not allowed a significant limitation of emissions since its inception.[17] The main problem is the determination of quotas which are not linked to actual outsourced costs but are arbitrarily fixed.

The ETS should see their influence grow over the course of this decade, however, it seems more appropriate to return to the fundamentals of the functioning of our society by putting in place solutions that protect our environmental, social, and economical ecosystem and which enable the implementation of the anti-dumping and anti-trust laws that already govern the market economy and lead to a "social market economy."

How to respect the laws of the market economy?

Governments must urgently put in place a mechanism in the form of, for example, Ecomalus (Eco for Economy & Ecosystem), which is not a state financing tax but an economic rebalancing that allows the outsourced costs to be integrated fairly into the price of products. These will be objectively

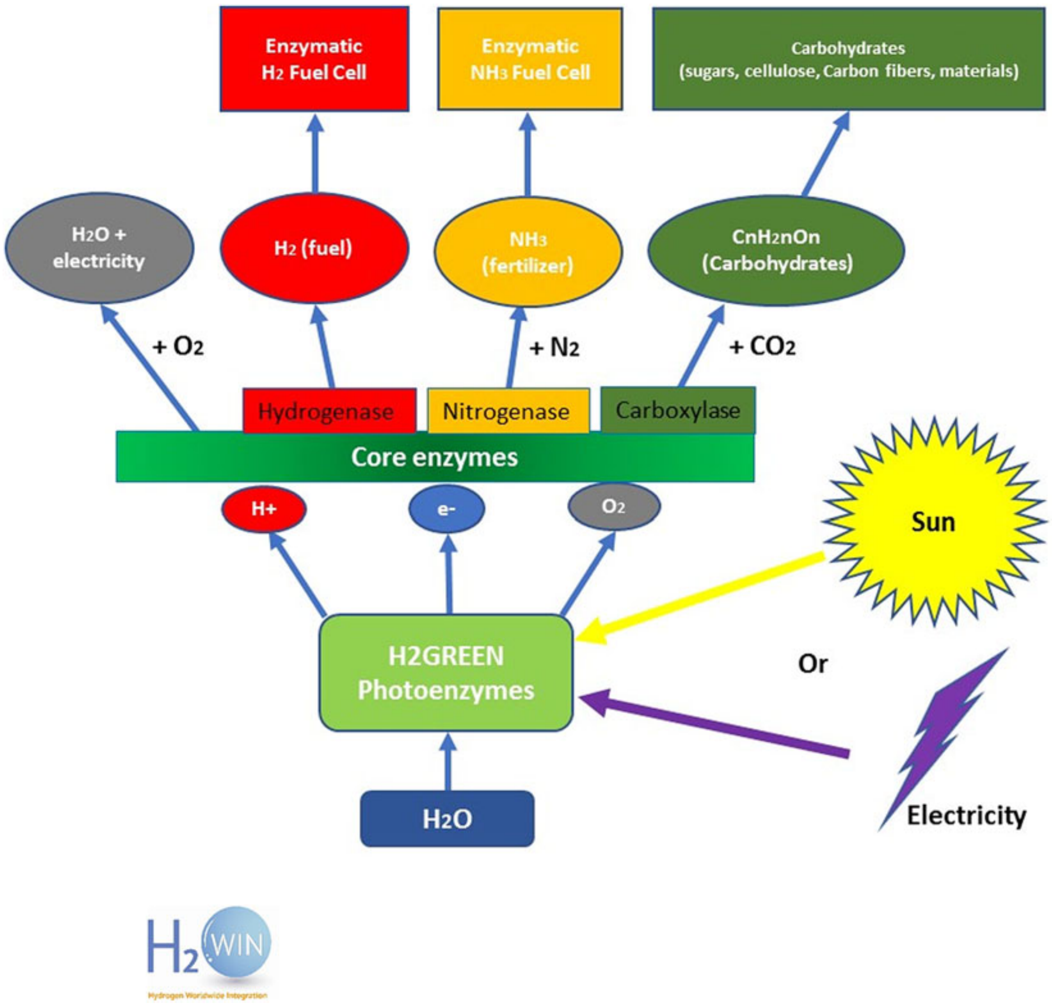


Figure 5. Perspective of a new industrial revolution. Source: H2WIN S.A.

evaluated by, for example, the UN, the WTO, WHO, or the IPCC, on the basis of actual costs related to pollution, health degradation, social dumping, financial risks, climate risks, risk of conflict, etc. ... currently borne by the community. This Ecomalus will then finance the reduction of the prices (e.g., in the form of Ecobonus) of products providing externalized benefits (train, hydrogen, bicycle, cycle paths, public transport, taxi, insurance, etc.) giving opportunity for local ecofriendly initiatives to rise.

We could call this closed-circuit system the MER for market economy respect. The starting point would be at the level of justice, which must be sought in order to enforce the laws of the market economy. The political level is necessary to put in place enforcement mechanisms and enforce existing laws.

An analogy can be made with the VAT system: For each product, the producer company takes into account Ecomalus and Ecobonus on the full value chain linked to its production, marketing, and recycling. The balance is then paid to or recovered from the centralized control body.

It is, therefore, a question of legally and precisely allocating the existing costs objectively established and not artificially incrementing the costs of products and services. The actual and outsourced costs would, therefore, be transferred from the community to producers/beneficiaries (cost shift). Of course, if the concept of a system such as the MER is a matter of indisputable common sense, its implementation is complicated, but VAT is not simple either...

Critical points of the MER about implementation requirements:

- Globality – It must be implemented at the global level and for all products/services (e.g., under the direction of the United Nations or WTO).
- Transparency (e.g., public access)
- Simplicity (single closed-circuit system)

"Ecomalus & Ecobonus": A compensation system, not an ecological tax

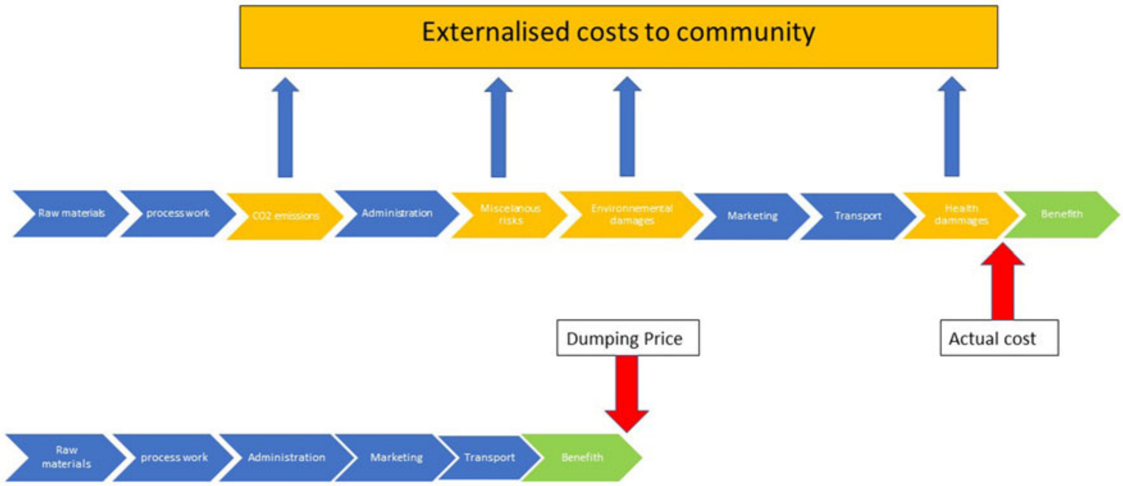


Figure 6. Value chain description with and without externalized cost. Source: H2life Foundation.

The term "ecological tax" is inadequate: The aim is not to finance the state but to restore the coherent implementation of market laws by compensating for the externalized real and not virtual costs. The calculation of ecological costs/benefits generated by products increases/decreases their price by offsetting.

Today's model of the most common value chain with environmental and health costs supported by the community as described in Fig. 6.

MER: A universal system

Besides ecology, the MER system could be applied to innumerable areas of noncompliance with the laws of the market economy, such as

- Social dumping leading to demographic explosion or emigration.
- Wars and the support of totalitarian regimes which are also outsourced "costs" of "secure" energy sources such as oil or uranium.
- The risk (nuclear, financial, health, ecological, etc.) in itself is also a cost too easily externalized to the community, it must be taken into account in the complete value chain of a product and, therefore, in the price of the product or service.

By definition, the MER will not increase the price of life in general but will shift from a real outsourced cost from the community to the product responsible for the cost. If an increase in the price of life were to occur, it would simply mean that the objective evaluation of outsourced costs is erroneous. This fair and just system will in the short-term induce virtuous behavior through retroactive self-regulation of human activity to achieve a metastable and dynamic balance with the planetary ecosystem.

Conclusions

The externalization of costs is obviously a dumping practice as they are not included in the selling prices. The fundamental principles of the market economy are not applied which lead to unfair competition with regards to products/processes taking care of the environment and health. This recurring problem is serious because, apart from socio-economic consequences, it kills the creativity and the implementation of new solutions and prevents energy technological solutions that protect the environment from supplanting fossil economy.

Many factors related to human activity, sometimes combined, contribute to the deterioration of the planetary ecosystem, which on the geological time scale represents a major sudden crisis. At the human time scale, a dramatic shift in environmental reference has so far caused the blindness of most global decision-makers. Among these factors, in our opinion, it is likely that heat emissions themselves are a major danger that forces us to get out of the "thermal age" to the "electroprotonic era" as a matter of emergency. In addition, the use of fuel cells is not only adequate to protect the climate with no CO_2 and lower heat emissions but also much healthier in terms of toxic emissions compared to combustion or nuclear energy.

However, it is a question of producing the energy vector that feeds fuel cells from renewable energy, in a localized way and without significant pollution. For these objectives, considering the enormous potential of the efficiency of light/electricity conversion by the photoenzymatic system of the PSII is essential. Of course, many problems of stability, loss of charges, or optimization of enzyme/electrode interfaces do exist, but these problems are not insurmountable and we will undoubtedly lead to the development of a cheap photoenzymatic system with a very high energy efficiency, stability, and capacity. At this level, an analogy can be done with the informatic technical evolution from the 1970s until now.

https://doi.org/10.1557/mre.2020.27

According to Gabor's law: "What can be done technically will necessarily be done ... in order to create new industries without considering whether or not they are desirable."[18]

Why not choose immediately the ideal and desirable solutions as they are technically possible?

Acknowledgments

The author thank professor F. Franck (University of Liege) and late professor F. Rappaport (University Paris Diderot) for the exiting discussions about photosynthesis. The author grateful to Dr. C. Plaigin (Public Service of Wallonia) and professor C. Theis (Lycée Josy Barthel Mamer) for their economic skills and understanding. The author also thank professor A. Braun (Empa) for its editorial help. The government of Wallonia is acknowledged for its financial support of the H2GREEN project.

REFERENCES:

1. Notz D.: Arctic sea ice in CMIP6. *Geophys. Res. Lett*. 47, 10 (2020).
2. IPCC Report (2019). Available at: https://www.ipcc.ch/reports/ (accessed July 16, 2020).
3. Chem Q. and Braun A.: Protons and the hydrogen economy. *MRS Energy Sustain*. 4, 1–4 (2017).
4. Kok B., Forbush B., and McGloin M.: Cooperation of charges in photosynthetic 02 evolution – I. A linear four step mechanism. *Photochem. Photobiol*. 11, 457–475 (1970).
5. Moser C.C., Page C.C., and Dutton P.L.: Tunneling in PSII. *Photochem. Photobiol. Sci*. 4, 933–939 (2005).
6. Rutherford A.W., Mullet J.E., and Crofts A.R.: Measurement of the midpoint potential of the pheophytin acceptor of photosystem II. *FEBS Lett*. 123, 235–237 (1981).
7. Klimov V.V.: Discovery of pheophytin function in the photosynthetic energy conversion as the primary electron acceptor of photosystem II. *Photosynth. Res*. 76, 247–253 (2003).
8. Walker D.A.: Biofuels, facts, fantasy and feasibility (2009). *J. Appl. Phycol*. 21, 509–517 (2009).
9. Lorge P.: Method for dissociating water using photosystem II (PSII). Belgian patent deposit 0598 (2013), EP 3044349 (2019), USP 10,519,553 B2 (2019).
10. Franck F., Juneau P., and Popovic R.: Resolution of the photosystem I and photosystem II contributions to chlorophyll fluorescence of intact leaves at room temperature. *Biochim. Biophys. Acta* 1556, 239–246 (2002).
11. Lorge P., Franck F., Remacle C., Job N., Cardol P., Godaux D., Caldarella G., and Ghysels B.: Core-enzyme presenting catalytic activity. *Pat. Pend*. EP19208893.8 (2019).
12. General Agreement on Tariffs and Trade - GATT (1947). Available at: https://www.wto.org/english/docs_e/legal_e/gatt47_01_e.htm (accessed June 26, 2020).
13. Treaty of Rome (1957). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3Axy0023 (accessed June 26, 2020).
14. World Trade Organization – WTO (1994). Available at: https://www.wto.org/english/thewto_e/whatis_e/tif_e/tif_e.htm (accessed June 26, 2020).
15. Kyoto Protocol (1997). Available at: https://www.kyotoprotocol.com/ (accessed June 26, 2020).
16. European Commission, EU ETS Handbook. Available at: https://ec.europa.eu/clima/publications_en#Ets (accessed June 26, 2020).
17. Andrew B.: Market failure, government failure and externalities in climate change mitigation: The case for a carbon tax. *Public Admin. Dev*. 28, 393–401 (2008).
18. Gabor D. Nobel Lectures, Physics 1971-1980, Editor Stig Lundqvist, World Scientific Publishing Co., Singapore, 1992.