Refrigerator as Model of How Earth's Water Manages Solar and Anthropogenic Heats and Controls Global Warming

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Key points

- Since the 19th century, anthropogenic heat releases heats the planet from inside as the Sun has been doing from outside for billions of years
- The equilibria between solid liquid vapor physical phases of water control heat exchanges and environmental temperature at the global level
- Hydrogen may be the source of energy of the future provided it can be shown beneficial regarding heat and life cycle assessments

Abstract:

The role of anthropogenic carbon dioxide (CO_2) in global warming is confusing. Experts predict that changes in ocean level and atmospheric temperature will increase considerably in distant future. On the other hand, loss of ices in the World is already dramatic and has increased over the recent years. Anthropogenic CO_2-related greenhouse effects may be responsible for the global warming; however ice imbalance remains to be explained in more details. We previously showed that estimated anthropogenic heat released between 1994 and 2017 was energetic enough to have caused the melting of a large part of the global ice lost during the same period. To complement this finding, the present work suggests that water on Earth behaves as a refrigerant and manages solar heat and anthropogenic heat similarly. It is also shown that the combustion of fossil hydrocarbons is releasing a huge amount of water stored for millions years in fossil hydrocarbon sources of energy. As anthropogenic heat is no longer negligible, minimizing CO_2 production may not be enough to control climate perturbations. Hydrogen is regarded as a climate-friendly alternative source of energy. The last part suggests that heat-cycle assessment from cradle to grave should be used in addition to life cycle assessment to compare hydrogen with other sources of energy in the search for ways to minimize anthropogenic heat release and its impact on climate changes.

Keywords: anthropogenic heat release; climate changes; heat cycle assessment; ice imbalance; life cycle assessment; water-interphase equilibria.

Plain language summary

Today, successive global warming-related reports predict dramatic atmosphere temperature and ocean rises in rather far future. These evolutions are assigned to extra greenhouse gas, particularly anthropogenic carbon dioxide generated by fossil sources of energy exploited in the world. However, everybody can observe that heat is also generated directly in the low atmosphere by the exploitation and the consumption of all sources of energy and not only fossil ones. Production of electricity and its exploitation by cars, trains, planes, electric appliances, etc… heat the entire environment. The present work compares solar and anthropogenic heat managements to the mechanism that controls the temperature in the interior of a refrigerator. It is concluded that water via ice melting and evaporation-condensation physical phenomena plays a role of refrigerant and manages solar and anthropogenic heats similarly. Ocean level and average global temperature rising could thus be less than presently predicted. Nevertheless cloud formation, rains, winds, storms, hurricanes, etc. are likely to increase in frequency and damages, as it seems to be starting to occur nowadays. Hydrogen is proposed as alternative to fossil sources of energy; however its potential must be assessed relative to both climate and environmental impacts.

Introduction

So far, the predictions of climate changes are based on hypotheses and calculations of evolutions for the far future as reported in successive Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2014; IPCC, 2019). These predictions result from an international consensus that predicts atmosphere temperature and ocean level rises dramatic in rather far future, a trend still small but nevertheless detectable today. This consensus is adopted almost universally although controversies exist that are frequently limited to non-peer-reviewed open access or magazine outlets [Dunlap & Jacques, 2013].

Until recently, the sun-dependent global climate was related to balanced inputs and outputs of electromagnetic infrared radiations and on effects of greenhouse gas, especially anthropogenic CO_2, occurring in the top of atmosphere (IPCC, 2014; NASA, 2009; Mackenzie & Lerman, 2006) without any specific consideration for conductive thermodynamics-related thermal exchanges in the low atmosphere**.** However, a small part of the solar energy is now considered absorbed by environmental elements (oceans, ice, land, etc.) where it causes heating predominantly in oceans (Hansen, et all, 2011**;** Trenberth et al., 2014). Estimates of imbalance were in the range of 1W/m2 in the early 2000s, i.e. about 10 ZJ (Trenberth et al., 2014). The residual heat that is not returned to space has to be globally balanced otherwise the Earth would grow warmer and warmer. Water cycle has been recognized for years as an important factor in climate control through evaporation-condensation phenomena despite limitations due to uncertainties on available global data (Allan & Liepert; 2010). In general, global ice was considered negligible relative to the ocean uptake of heat imbalance (Hansen et al., 2011). Based on outstanding facilities including satellites, NASA reported recently on sea ice and its role on the polar environment (Scott & Hansen, 2016). The occurrence of dramatic global ice loss has been clearly observed, especially over the recent years; this at the levels of ice caps, sea ice, glaciers as well as permafrost (Rignot et all, 2019; Slater et all, 2021). However, ice loss is generally considered as a source of ocean rise (Allan & Liepert; 2010). The possible contribution of anthropogenic heat release (AHR) to global warming has been neglected in the past. The context and the history are well introduced in a recent publication (Yang et al, 2017) in which the authors proposed an algorithm to evaluate global AHR. This approach consists in calculations based on heat energy estimates derived from urban zones. Although there were some limitations, the algorithm provided multi-scale anthropogenic heat information said reliable and useable for further research on regional or global climate changes and on urban ecosystems despite problems raised by difficulties to establish ratios for converting energy consumption to anthropogenic heat.

We recently proposed a different approach (Vert, 2021) based on fundamentals of chemistry and physics and on annual global energy consumptions derived from various sources (fossil ones, biomass, nuclear electricity, etc.) found converted in oil-equivalents (Martin-Amouroux, 2015; BP, 2019). In the absence of relative yields in work and heat for each source of energy, AHR was limited to 60% of the global energy consumption (Manowska, & Nowrot (2019). It was shown from the resulting AHR estimate that anthropogenic heat released between 1994 and 2017 had provided enough thermal energy to cause the melting of a large part of the ice lost reported recently for the same long period (Slater et all, 2021). The comparison was used to speculate about evolution of the global climate in the absence of possibility to demonstrate climate-related phenomena experimentally.

Regardless of the mechanism, solar radiations have been heating the global environment without dramatic heat accumulation despite occurrence of short and long local ups and downs periods for billions years. Nowadays, anthropogenic heat releases generated by the energy produced and consumed by humans is no longer negligible. Therefore, it has to be managed similarly and simultaneously to solar heat imbalance to keep Earth's environment and climate under relative control. Indeed, the Earth can be schematically considered as a huge globe whose land, solid matters, surface water and atmosphere are heated through excitation of molecules by interaction with solar electromagnetic radiations. Without compensation to keep the temperature compatible, the accumulated heat would have precluded the appearance of life on Earth. If the greenhouse effects well accounts for the 18°C excess of Earth's temperature relative to what it would be in the absence of atmosphere, they cannot explain the absence of accumulation in case of imbalance. Rejection of some infrared electromagnetic waves to space is the mechanism largely adopted in the world (IPCC, 2014].

A few thousand years ago, humans began to use biomass as sources of heat and light energies. The resulting AHR remained negligible compared with solar inputs until about 150 years ago when humans began to exploit fossil sources and, more recently, nuclear plants and renewable resources for the production of electricity; these energies being needed to satisfy work, heat and comfort. The side effect was the appearance of much greater amounts of anthropogenic heat releases that are now considered as able to affect the climate (Yang et al.; 2017). The corresponding heat had to be compensated otherwise the planet would have grown warmer and warmer over the years. With this regard, Earth can be compared to a mammalian body whose metabolism generates heat in a closed space, the body. The body has to be cooled down to keep its temperature constant. Based on this analogy, the present article aims to compare Earth's water with a simpler model: the refrigerant that controls the temperature inside a refrigerator; another case where inner heat has to be eliminated.

The refrigerator

From a thermodynamic viewpoint, a refrigerator is based on a simple rule: "when two substances are in contact, the hot one supplies heat to the cold one up to equilibrium". In a refrigerator, the transfer of heat proceeds by evaporation-condensation of a volatile fluid: the refrigerant. Heat is absorbed locally by the evaporation of the fluid, transported by the gas phase, and released from this gas by condensation outside. To some extent, this is how the temperature of humans and mammalians is fixed. An amount of warm liquid water present in the body is expulsed during breathing and through the skin by perspiration. The sweat cools the surface and the interior of the body by evaporation in the atmosphere until perspiration is no longer necessary.

The transfer of heat from a hot medium to a cold one is spontaneous and rather slow. In contrast, heat exchanges from a cold medium to a hot one cannot be spontaneous. Some energy must be supplied. It is the role of the compressor present in air-conditioning machines and refrigerators. For humans, there is no compressor and the pressure in tissues is the sole driving force that pushes water outside prior to its evaporation to keep the inner temperature constant. A schematic representation of a refrigerator is shown in Figure 1. The main stages of the temperature controlling process are the following:

Evaporation

From 1 to 2 in Figure 1, the volatile refrigerant enters the inner evaporator as a liquid. Going through this multi-tube device, the liquid absorbs part of the heat present in the closed space, including the foods which are in it. As a result, the liquid is turned to gas at the outlet of the evaporator while the temperature inside the closed space decreases slightly.

Compression

From point 2 to point 3, the gas is pressurized in the compressor where it is super-heated by compression and then transfered to the multi-tube condenser located outside, generally in the back.

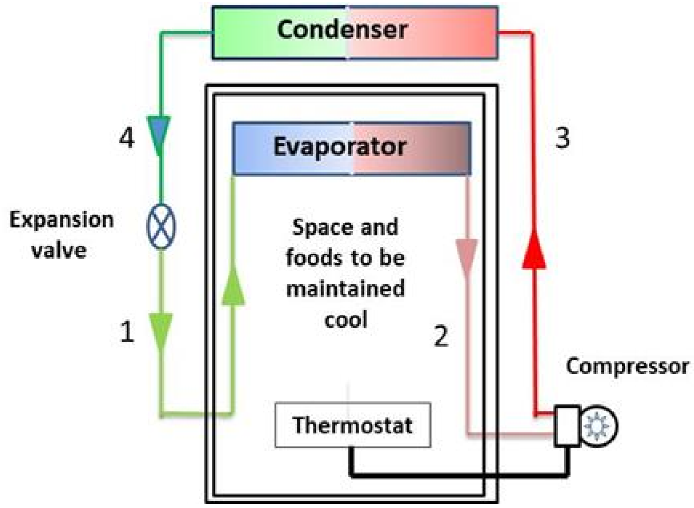

Figure 1: Schematic representation of a Vapor Compression-Refrigeration cycle.

Condensation

From point 3 to point 4, the hot pressurized gas enters the condenser. The initial part of the cooling process in the condenser is contact with the outer cold surface that decreases the temperature of the gas and finally turns it back to liquid. This step is where the inside thermal energy absorbed by the refrigerant at the evaporation stage is vented out to atmosphere. The condenser in the back of the refrigerator is hot as it can be easily observed.

Expansion of the subcooled and highly pressurized refrigerant

From point 4 to point 1, the high-pressure subcooled liquid passes through the expansion device which reduces its pressure and controls the flow of liquid into the evaporator (stage 1). The cycle is repeated until the temperature in the refrigerator reaches the temperature set at the thermostat otherwise the inner temperature would continue to decrease with ice formation on the walls of the internal compartment, something everybody can observe in a freezer.

Application to Solar energy management on Earth

The water dependence of solar and anthropogenic heats has been detailed in a previous article (Vert, 2021). The ground surface, the water (oceans, seas, ponds and rivers), the atmosphere and the ice (polar caps, glaciers and floating ices) have been heated by the Sun for billions of years in the past without heat accumulation. These environmental elements can be compared to the foods inside a refrigerator where the temperature is controlled. However, there are differences. The compressor present in Figure 1 to allow and speed up the thermal exchanges from cold inside to hot outside is not necessary and is replaced by chaotic turbulences in atmosphere (winds, streams, tornadoes, hurricanes) and oceans (hot and cold streams) to dispatch heat within the whole environment.

The condenser is replaced by the cold zone of the atmosphere where vapor condenses to form clouds which release the heat stored at the evaporation stage. The refrigerant present in the cooling circuit of the refrigerator is replaced by water, and the heat energy released during cloud formation is eliminated from the high atmosphere by radiation to the space as in the case of greenhouse effects. The whole process is schematized in Figure 2.

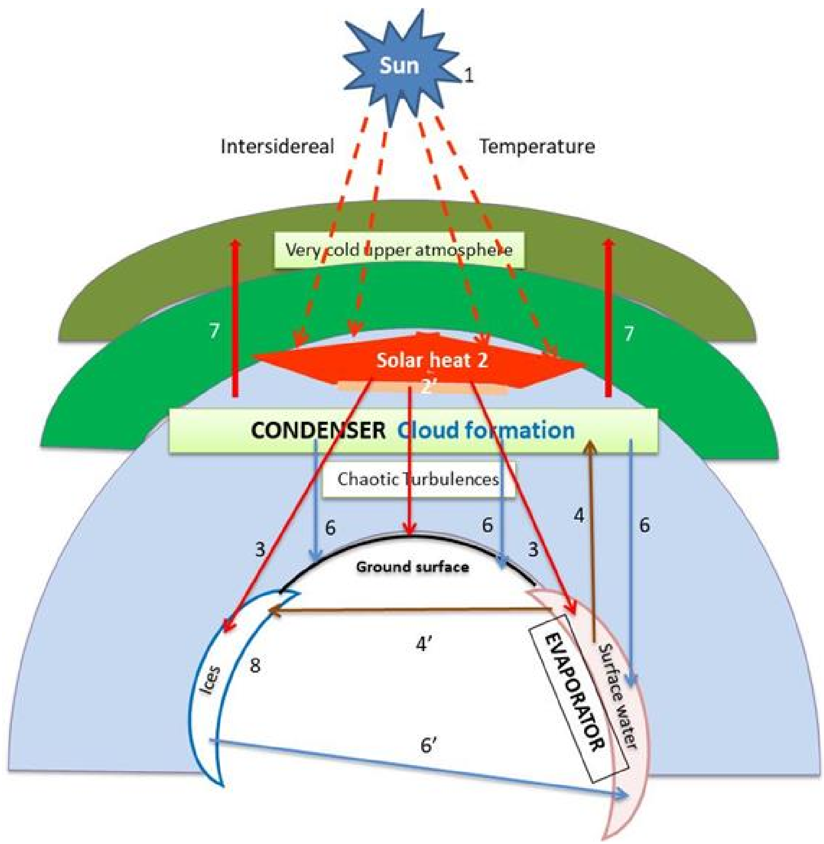

Figure 2: Schematic representation of the machinery that manages residual solar heat energy through water phase exchanges.

In this scheme, the Sun (1) heats the whole environment as everybody feels it under sunshine (2 and 3). Greenhouse effect-dependent radiative energy (2') comes in addition. Atmospheric turbulences dispatch these heats within the multilayered atmosphere in contact with the very cold intersidereal medium on one side, and with ground, ice and surface water on the other side. The supply of geothermal heat is generally considered as negligible. The temperatures of the ground surface and of the ocean tend to increase but part of the heat causing the rise is slowly balanced by the melting of ices (4' and 6') over the whole globe. The other part is balanced by the process of evaporation (evaporator) that cools ocean and surface liquid water (the refrigerant) and transfers the corresponding heat to the troposphere as warm vapor (4). The air enriched in warm vapor being less dense than dry air rises up to a zone cold enough to condense the vapor as dispersed droplets forming clouds while the heat stored in the vapor is released to the upper cold atmosphere which irradiates it away (7). Rains (6) close the cycle and return cool water (or even ice) to the surface. Such cycle is not uniform. In reality, the Sun does not heat continuously. Earth inclination and rotation lead to cyclic heating and cooling according to day and night, summer and winter, North and South hemispheres, and the Sun long cycles as well. The process of melting and reformation of ices is thus cyclic with ups and downs as in a refrigerator. If all the ice disappears inside the refrigerator, the inner temperature starts rising up to the outside one unless the thermostat restarts the cycle to reform ice. In the case of Earth, when all the ice will have melted, management of heat, regardless of its origin, will be handled by the dominance of the right shift of evaporation vapor condensation interphases equilibria, i.e. up to the formation of a thick cover of clouds that, finally, will block, like durst particles are said doing, the input of solar heat leading to regeneration of ice on Earth (Miller et al., 2012)

The evolution after the appearance of Anthropogenic Heat

The controlling process described in the previous section worked for billions of years to manage Sun and biomass-related heat by cyclic ice melt and reformation and by radiation to space. The exploitation of fossil oil-derived energy started bringing in extra heat in the middle of the 19^{th} century. Then, natural gas and more recently electricity provided more heat to be balanced like when Sun was the only source of heat. The new situation is schematically represented in Figure 3.

The comparison between Figures 2 and 3 does not reveal great change relative to the whole thermal machinery. The solar energy still heats the Earth dominantly (2) but a contribution of anthropogenic (2") is added to the sun-dependent greenhouse one (2'). On the other hand, the released anthropogenic heat from fossil sources and electricity sources complements the solar heat supply and thus contributes as a surplus of heating dispatched essentially in the low atmosphere and in surface water (4' and 4"). In the low atmosphere, this surplus of heat is managed by ices melt and water as in the case of Figure 2 and leads to greater ice melting (8) and water evaporation (4).

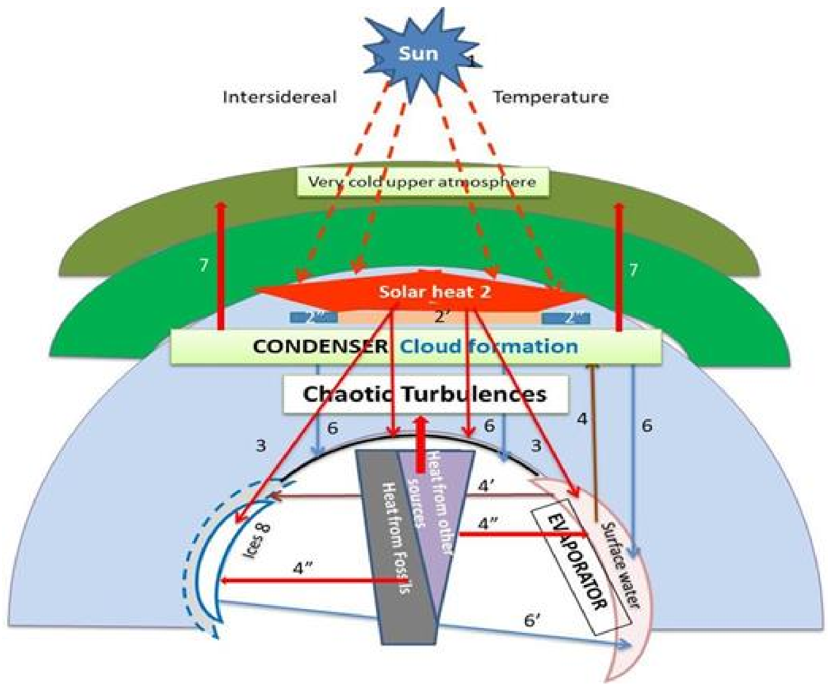

Figure 3: Schematic representation of the management of increasing amount of anthropogenic heat through evaporation-condensation-evaporation and ices melting.

The greater amount of warmed vapor rises to the cold zone of the atmosphere where the stored heat is released and forms more clouds than when the Sun was the only source of heating. The cloud water goes back to surface water as rains and snow or ice (snow and hailstones) (6). Having to handle more thermal energy, local chaotic turbulences (hurricane, tornado, rain, flooding, etc...) become more important and more frequent. The Sun activity is unchanged with daily, annual and longer cyclic ups and downs modulations. In contrast, AHR occurs almost continuously over days and nights, this in acceleration over the years so far. This mechanism provided a consistent explanation to ices imbalance. Unfortunately, the planet, like the human body, is too complex and available data too general or not enough accurate to take into account all the more or less interrelated factors to be involved in mathematic quantification.

What about the water generated from fossil hydrocarbons?

For a majority of scientists who try to understand and account for climate changes, the anthropogenic heat generated by humans and human's activities is negligible relative to the effects of greenhouse gas, especially those related to the CO_2 issued from fossil sources of energy. Among these sources, coal, which is mainly composed of carbon, generates hot carbon mono and dioxide on burning but no water, at least directly. In contrast, all the hydrocarbons (oil, natural gas, and biomass) generate hot CO_2 from the carbon content and hot water vapor from the hydrogen one. However, once the heat is transferred to the environment, the cooled water previously chemically stored in hydrocarbons constitutes a surplus of water on Earth.

Quantifying the amount of such extra water is as difficult as quantifying heat releases. Nevertheless, data on the overall production of fossil oil and natural gas are available and provide means to estimate the extra water produced by the combustion of hydrocarbons of fossil origin. Between 1870 and 2018, about 180 Gt of oil and 30 GToe of natural gas have been extracted (Martin-Amouroux, 2015; BP, 2019) i.e. about 210 Gt of hydrocarbons. To compensate the complex composition of oil and natural gas, one can assume these fossil hydrocarbons, including methane (CH_4), composed of alkanes only, the general chemical formula of which is C_nH_{2n+2} reasonably simplified to nCH_2. Accordingly, 210 Gt of oil equivalent contain c.a. 180 Gt of carbon and 30 Gt of hydrogen. From the general equation $CH_2 + 3\ O_2 \rightarrow CO_2 + H_2O$ + heat where 14 g of hydrocarbon (12 + 2) generates 44 g of CO_2 (12 + 32) and 18 g of water (16 + 2), both compounds being hot, one can deduced that 210 Gt of hydrocarbons produced about 270 Gt of extra hot water that joined the pool of water already present in 1870. Based on the water released from 28,000 Gt of ice lost between 1994 and 2017 (Slater et al., 2020) the estimated 270 Gt of extra water cumulated since 1870 corresponds to c.a. 1 year of recent ice loss and, thus, it is rather small and negligible to increase ocean level so far. This water was inserted in the environment and dispatched between biomass, atmosphere, ground, ice and liquid water. Whether the part that joined the 13,000 Gt of water vapor in the atmosphere may have added extra greenhouse-type heating considering the much higher efficiency of water relative to CO_2 has not yet been addressed as far as we know. Anyhow, AHR will become more and more problematic if oil and natural gas consumption continues to grow over the years as is part of the energy production (Zou et al., 2016). Fighting the sources of CO_2 is a solution in the context of surplus of solar greenhouse effects. However, this solution may appear insufficient if ices imbalance is definitely related to the extent of anthropogenic heat. Replacing fossil sources of energy by zero-CO_2 ones may permit to fight the effects of greenhouse gas as recommended in IPCC's successive reports. However, unless something is done to limit de production of anthropogenic heat, it will continue to grow with the global energy production and consumption in response to the demand in energy necessary to satisfy needs of comfort, activities, and more generally economy of the predicted growing population

Can hydrogen be the solution?

Apart from limiting the growth of population, hydrogen is regarded today as an attractive alternative to replace fossil fluid in the future (Johnston et al, 2005). Basically it can be produced from water and it regenerates water after exploitation as source of energy according to the following scheme: electric energy + $H_2O \rightarrow H_2 + ½\ O_2 \rightarrow H_2O$ + energy. So far, hydrogen is primarily produced from fossil resources and catalysts. Catalytic electrolysis will be of particular interest only if the energy needed to dissociate water in hydrogen and oxygen is produced by low heat-producing renewable sources of electricity (Gardner, 2009). What is presently missing to decide whether a source of energy is better than another relative to AHR is a heat-cycle assessment from cradle to grave, as it is currently done with life-cycle assessment to compare processes and materials relative to their impact on the environment (Muralikrishna & Manickam, 2017). So far, it seems that no quantitative information is available relative to heat-cycle of wind turbines and of other CO2-free sources of electricity in comparison with the other sources of energy in terms of thermal impact on the climate. Hydro-electricity may be of particular interest in this regard. However, one can wonder whether large enough amounts of hydrogen will be producible from CO_2-free sources of energy. It will be the task of specialists in thermodynamics working together with climatologists and chemists to make the necessary assessments.

Conclusion

To complete the previous analysis that led to reasonably correlate an estimate of ice imbalance observed between 1994 and 2017 to an estimate of anthropogenic heat released during the same period of time, it was shown that heat management on Earth can be compared to the system which controls the temperature inside a refrigerator. The comparison showed that water acts as a refrigerant to transfer absorbed solar heat, and anthropogenic heat as well, to the upper atmosphere cooled by radiative transfer to space as proposed by the greenhouse effect hypothesis. It was also shown that on Earth, as in a refrigerator, ice melting combined with evaporation-condensation equilibrium are means to control global warming and ocean rise. This work emphasized also that the combustion of hydrocarbon-based sources of energy generates, since they are exploited, new hot vapor that joined, once cooled, the water existing before oil and gas being exploited. However, its estimated amount is still minor compared to the water generated by ice loss. Finally, heat-cycle assessment is proposed to compare the different sources of energy and determine which ones may replace those currently exploited. Hydrogen seems to be an interesting candidate if it can be produced by electrolysis with competitive and acceptable heat-cycle and life-cycle assessments; an essential condition to respect both the climate and the environment. Such evaluations will have to be done by suitable interdisciplinary consortia attempting take into account the complexity of the Earth.

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Data availability statement

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Conflict of Interest

The author does not have any conflict of interest to report

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